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This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

Walter Summers,
for KENNETH R. BOFF, Chief
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This report combines an annotated bibliography about situation awareness (SA) with four papers that discuss central issues for SA research. The report was compiled to support the Armstrong Laboratory's Situation Awareness Integration (SAINT) team. The annotated bibliography includes the citations and reviews of over 200 articles that discuss SA research or the role of SA in operational systems. These articles are indexed by keyword and author(s). The four papers address the definition of SA, the cognitive processes involved in SA, the operational role of SA, and the initial results of the SA research program conducted by the SAINT team.

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PREFACE

This report was prepared in the Human Engineering Division, Crew Systems Directorate of the Armstrong Laboratory (AL), Wright-Patterson Air Force Base, Ohio. The work was performed under Project 7184, "Man-Machine Integration Technology," Task 718414, "Operator Workload Assessment."

The authors would like to thank Ms. Laura Mulford for her unstinting and steadfast support in the preparation of this report. Also, the authors would like to thank Michael Gravelle and J.N. Hecht for their efforts in conducting the computerized literature searches.

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INTRODUCTION

This Technical Report is part of the research activity conducted to support the US Air Force's Armstrong Laboratory Situation Awareness Integration (SAINT) team's efforts. The SAINT team was formed to organize the research activities of separate groups within the Armstrong Laboratory to investigate Situation Awareness (SA) and its relevance to the Air Force.

The Technical Report is divided into two main sections: Section I presents four papers reviewing aspects of the SA concept and research. Section II is an annotated bibliography of published SA papers.

Section I - Papers

Section I begins with a paper by Capt Cynthia Dominguez that addresses the controversial issue of a definition for SA. The need for an agreed-upon definition has been lamented in a very large proportion of the SA research papers. Many researchers have already attacked this problem. Capt Dominguez's paper will review these earlier attempts to determine whether a consensus definition can be constructed.

The second paper, by Dr. Michael Vidulich, was originally written during the early stages of the SAINT team's response to SA concerns raised by the Air Force's Chief of Staff. The paper attempted to describe some of the relevant issues from cognitive psychology that could impact upon an SA research program.

The third paper was written by Lt Col Eric Vogel. Lt Col Vogel has a strong background in Air Force tactical airlift operations. Inasmuch as the SA concept originated with the operational community, it is appropriate that their concerns be directly represented in this report. Lt Col Vogel's paper should be of especial interest because it addresses SA in the domain of tactical airlift. Traditionally, discussions of SA have been dominated by its role in a fighter aircraft cockpit. In demonstrating the relevance to a new domain, Lt Col Vogel's paper shows the generality of the SA concept.

The final paper of Section I is by Dr. Grant McMillan. It provides a summary of the SAINT team's initial research project that responded to SA concerns raised by the Air Force Chief of Staff, General McPeak. This paper started as an edited version of a November 1993 presentation to the Air Force Scientific Advisory Board, but it has been updated to include the data and results that were presented in a briefing to General McPeak in April 1994. As can be inferred from the paper, this program had several components that are very likely to be presented as separate reports of considerably more detail. Nevertheless, we feel that an overview of this large program will be of interest to the SA research community.

Section II - Annotated Bibliography

The second section of the report is an annotated bibliography of SA papers. It must be acknowledged that this bibliography is not exhaustive. Although SA is a relatively recent term, it would be impossible within any reasonably-sized effort to find and review every paper that has invoked the concept. Nevertheless, we have attempted to collect papers from a wide enough group of sources to be representative of the extent of the SA concept within the literature and to review enough papers to form a critical mass of information for a researcher trying to become familiar with the field.

The accumulation of papers started with the personal collections of the reviewers. This was supplemented by a computerized literature search of the NASA-RECON, Defense Technical Information Center, PsychINFO, and Energy Science & Technology databases. The computerized literature search was conducted by Michael Gravelle and J.N. Hecht of the Crew Systems Ergonomics Information Analysis Center (CSERIAC). Finally, manual surveys of numerous journals, proceedings series, and magazines were conducted. In particular, several years of *Aviation Week & Space Technology* were surveyed to collect examples of how SA was used by the operational, rather than the scientific, community.

Of the final collection of papers, over 200 were reviewed and categorized. The citations, reviews, and lists of relevant keywords are presented in the annotated bibliography. In order to assist in accessing the most relevant citations, the bibliography is followed by a keyword glossary and two indexes. The keyword glossary provides a description of the keywords used to classify each of the entries in the bibliography. The keyword index lists all of the entries, identified by number, that had a given keyword assigned to them. The second index provides a listing of all of the authors cited in the bibliography and the bibliographic entries with which each author was associated.

The authors of this report hope that the community of researchers investigating SA will find the papers and bibliography included in the report to be helpful.

SECTION I -

PAPERS

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CAN SA BE DEFINED?

Capt Cynthia Dominguez
Crew Systems Directorate
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Introduction

This paper undertakes the task of analyzing situational awareness (SA) definitions in the open literature in order to establish the elements which should comprise a definition of SA. One consolidating definition is then presented.

When a new construct emerges and gains momentum in the academic and applied communities with such force as has situational awareness, it is only natural that those of us who pursue its meaning and its measurement should seek to define it as well. Unfortunately, the lack of an agreed-upon definition of SA has itself been a defining characteristic of SA from the start. As was the case with mental workload, there are many definitions, and although the concept is accepted as important without qualification, nobody is willing to accept anybody else's definition (Wickens, 1992).

This definition analysis effort is undertaken with a high level of SA, at least in relation to current publications on the subject of SA, since reviewing numerous papers en route to creating an annotated bibliography provides an overall big picture of the field. Armed with the thoughts and perspectives of a multitude of practitioners and researchers, the goal of this paper is to integrate the available information, to hash through and distill current thinking in order to cull out the most vital components of each perspective. Throughout this process, the aim is to clarify the essence of SA into a definition which succinctly encapsulates its nature.

Why do we need a definition of SA? Lack of a standard definition does not hinder those in search of a research project involving SA, and certainly doesn't hold back those of us who are already involved in some aspect of SA research. Sarter and Woods (1991) point out that a significant hindrance in any effort to cull the critical components of SA into a definition is the context-dependent nature of the concept: what is relevant information in one flight situation may have little impact in another. They imply that any definition general enough to account for the context-sensitivity of available flight information will probably be too broad to be of use. A broad definition describing how cognitive processes work to achieve SA is certainly in danger of being a general description of human information processing.

Yet, in spite of this pitfall, it seems that a condensed verbal summary of the general process of sifting through and using environmental and internal information **in flight** can be a critical tool. We must be able to represent the SA construct in a manner that users, engineers, and lay people can understand and appreciate. In addition, we need greater understanding of the concept for the purposes of moving forward with meaningful research. Consider the number of SA definitions presented in Table 1. Each definition may generate a unique train of study designs and influence the choice of measures used in these studies, as was the case with mental workload.

Table 1.

Definitions of SA

Definitions	Source
Conscious awareness of actions within two mutually embedded four-dimensional envelopes.	(Beringer and Hancock, 1989, p.646)
A pilot's continuous perception of self and aircraft in relation to the dynamic environment of flight, threats, and mission and the ability to forecast, then execute tasks based on that perception.	(Carroll, 1992)
The ability to extract, integrate, assess, and act upon task-relevant information is a skilled behavior known as 'situational awareness.'	(Companion, Corso, Kass, & Herschler, 1990)
The accurate perception of the factors and conditions that affect an aircraft and its flight crew.	(Edens, 1991, p. 7. Schwartz, 1993, uses this definition with "during a defined period of time" at the end.)
The perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future.	(Endsley, 1990, p.1-3)
The knowledge that results when attention is allocated to a zone of interest at a level of abstraction.	(Fracker, 1988, p. 102)
The pilot's overall appreciation of his current 'world.'	(Gibson & Garrett, 1990, p.7-1)
One's ability to remain aware of everything that is happening at the same time and to integrate that sense of awareness into what one is doing at the moment.	(Haines and Flateau, 1992, p. 43)
<u>Where</u> refers to spatial awareness. . . <u>what</u> characterizes identity awareness, or the pilot's knowledge of the presence of threats and their objectives, [as well as] engine status and flight performance parameters. <u>Who</u> is associated with responsibility, or automation awareness; that is knowledge of 'who's in charge.' Finally, <u>when</u> signifies temporal awareness and addresses knowledge of events as the mission evolves.	(Harwood, Barnett, and Wickens, 1988, p. 316)
The ability to envision the current and near-term disposition of both friendly and enemy forces."	(Masters, McTaggart, and Green, 1986, p.5; Stiffler, 1987)
Awareness of conditions and threats in the immediate surroundings.	(Morishige and Retelle, 1985, p. 92)

The ability to maintain an accurate perception of the surrounding environment, both internal and external to the aircraft as well as to identify problems and/or potential problems, recognize a need for action, note deviations in the mission, and maintain awareness of tasks performed.	(Prince and Salas, 1993; cited in Shrestha et al., 1993, p.10)
[Situational awareness] means that the pilot has an integrated understanding of factors that will contribute to the safe flying of the aircraft under normal or non-normal conditions.	(Regal, Rogers, & Boucek, 1988, p.65)
Situation awareness refers to the ability to rapidly bring to consciousness those characteristics that *evolve* during flight.	(Wickens, 1992, p.2)
The pilot's knowledge about his surroundings in light of his mission's goals.	(Whitaker & Klein, 1988, p.321)

The problem with this divergence of effort is that we are left with no unifying construct on which to focus our efforts. Thus, when challenged to assess SA in an operational environment, it is impossible to determine whose definition, whose line of research should be used as a basis for this work. And, as a side benefit, if by some chance there becomes an "agreed-upon" definition of SA, that fact in itself will be important to be able to assert that the study of SA is thus different from the study of workload.

Approach. To accomplish this breakdown of the components involved in SA, the definitions available in the literature (listed in Table 1) were dissected and compared. The **process** and/or **product** described in each definition was identified, and each major element of each definition was culled out and evaluated. The process of SA refers to **how** SA is developed and maintained during flight, while the product is the resultant, elusive **thing** we call SA itself (Tenney, Adams, Pew, Huggins, and Rogers, 1992). Product and process of SA are discussed in detail below. Common themes were extracted from the definitions; the criterion for discussing a common component or theme in this paper was whether it appeared in three or more definitions.

Abilities

"Ability" is clearly a commonly used word in defining SA. Five of the definitions in Table 1 mention ability. The use of the word "ability" brings out an important dichotomy about the concept of SA. SA is used interchangeably as an ability, akin to "the right stuff," which a pilot either has or hasn't got, and as a state of mind which may be achieved or not on a flight, or which may be lost at certain times during a flight. Researchers examine SA from both perspectives. The Air Force and other military services are interested in a basic ability to achieve SA because of its potential impacts on both training time and the selection process. (In another part of this report, Grant McMillan discusses an Air Force effort which looks at SA both through ability measures and moment-to-moment performance measures.)

Even so, possessing the ability to achieve SA can be undermined by several factors which impact in-flight SA. Examples of these factors include fatigue, lack of recent training, emotional state, and mind-altering substances. A pilot may have the ability to perform the cognitive processes which result in SA without actually achieving it on a particular flight. Because quality of SA is subject to change from flight to flight and even from moment to moment during flight, a definition which describes **how SA is attained in flight** as opposed to whether the pilot is **able** to achieve it in general is preferred. Therefore, "ability" will not be included in this definition of SA.

Perception/Extraction

Companion, Corso, Kass, & Herschler (1990) state that "the ability to extract, integrate, assess, and act upon task-relevant information is a skilled behavior known as 'situational awareness.'" A definition of SA should minimally include the "extraction" component they identified. Extraction is more tied into **actively** perceiving than using the term perception (perception is used by Edens, 1991; Endsley, 1990; Carroll, 1992; and Schwartz, 1993). Both terms lead to an understanding of the situation through sampling the environment; this is usually accomplished by scanning the airspace, cross-checking the instruments, and watching and listening to other crewmembers. This element is what Endsley (1990) refers to as Level 1 SA: "The pilot perceives the elements (e.g. an aircraft, a mountain, a warning light) that are present in the environment, along with their relevant characteristics (e.g. color, size, speed, location)." (p.1-2) Schwartz (1993) states that SA begins with "accurate perception...," while Carroll has adopted a definition which calls for "continuous perception."

An insightful perspective on this element of SA is given by Tenney et al. (1992), who argue that current definitions of SA differ as to whether they emphasize the product or the process of SA. "The state of awareness with respect to information and knowledge is the product. The process, in contrast, involves an active and dynamic series of cognitive activities." (Tenney et al., 1992, pp. 2-3)

Tenney et al. state that both types of definitions "capture the key features of SA: an understanding of the meaning of events and the ability to anticipate the consequences of taking or failing to take particular actions." (p. 2) They go on to present a unique view of SA, derived from Neisser's theory of the perceptual cycle, which is rooted in Gibson's theories on the ecological approach to visual perception. Perception is seen as a resonating cycle of sampling from the environment, mapping onto schema, and using the schema to further direct the sampling; the environment in turn impacts and modifies the schema (Neisser, 1976, cited in Tenney et al., 1992, p.5). Endsley (1990) likewise emphasizes the active nature of perception; she states, "the pilot SA/decision making process can be viewed as a dual process whereby active schema and scripts are dictating which information to focalize attention on, and simultaneously the presence of certain objects or attributes in the environment will activate new schema in long-term memory." (p. 1-3)

This cyclical process emphasizes extraction over perception to describe the active manner in which a pilot acquires the information he or she needs. For example, on a low-level bomb run, an experienced pilot knows what information is needed to complete the run successfully; this

information is actively extracted from instruments, environment, other crewmembers, and from internal knowledge about the mission. The pilot is not simply a sponge; query and discrimination are ongoing continuously. The process of extraction reveals intelligence which updates the product SA, which in turn directs the pilot's attention where it's needed next. The beauty of this approach is that it intertwines the process of developing SA with the resultant SA, demonstrating the interdependence of the two. By subscribing to the notion that perception is actively accomplished through extraction, a persuasive case can be made for a definition of SA which accounts for both the process and product involved.

The Product

Up to this point, the importance of information extraction in SA and the usefulness of combining the product and the process of SA into one definition have been established. The next element which surfaces from several definitions of SA concerns how information extracted from the environment is incorporated into the pilot's overall picture, or "coherent internal world view" (Goodson et al., 1990, p.2). This element is referred to by various authors as "comprehension," "integration," "bringing to consciousness," and "integrated understanding," which bring to mind the process of melding previously-known and freshly extracted information into a cohesive picture. Endsley's 3-Level model of SA (1990, p. 1-2) identifies Level 2 SA as "a holistic picture of the environment" which integrates the perceived environmental elements from Level 1. In line with the paradigm used to categorize SA definitions in this paper, this picture is essentially the **product** of SA.

Many cognitive theories have been developed to describe the processes of comprehension, integration, and understanding involved in attaining SA. In fact, several authors have written extensively on the cognitive underpinnings of the SA construct (e.g. Endsley, 1990; Fracker, 1988; Tenney et al., 1992; and Vidulich, this report.) Throughout the literature, SA (the product) is referred to as a mental model. Such a mental model is formed based on all relevant information that the pilot has absorbed and integrated which impacts the current flight. It combines earlier knowledge and experience with the current flight's briefing information and up-to-the minute cockpit status. The pilot's mental model is continuously being updated, and it is used to predict future trends. It is a Gestalt, according to Gibson and Garrett (1990), which is greater than the sum of its parts. Sarter and Woods (1991) state that adequate mental models are a prerequisite for achieving SA. (See Harwood, Barnett, and Wickens, 1988, for an in-depth discussion on SA and mental models)

Although there is controversy over the definition of mental models (Rowe, Cooke, Neville, and Schacherer, 1992), the concept is useful in that it facilitates understanding of the nature of human information processing as it applies to complex, dynamic tasks such as piloting an aircraft. These models are like schema, referred to by Tenney et al. (1992) above, in that they are developed and improved-upon through experience and training. Schema are conceptual long-term memory structures used to organize task-related and other information. Cues activate schema, causing them to enter working memory where they update the working mental model.

The lack of schema or mental models greatly increases the mental workload for novice pilots. For example, first-time pilots often cite the difficulty of interpreting and making radio calls. As a pilot's hours accumulate, he or she develops a conceptual framework in long-term memory for understanding and responding to radio calls; these calls, over time, become almost second nature. Over time, the processes involved become "automatic," requiring little effort and posing no load on working memory (Schneider and Shiffrin, 1977). Hartman and Secrist (1991) describe this process nicely: "Automatic processes develop as a result of long-term, consistent mapping between stimulus arrays and response repertoires." The process of training a pilot really revolves around developing in the pilot a set of knowledge structures which can be activated quickly, without conscious thought, and with little or no attention, so that the aircraft can be operated in a dynamic, challenging environment without over stressing the pilot's working memory.

All of these constructs (mental models, schema, automatic processing) have been used to describe how pilots achieve SA, as have other constructs for understanding information processing which are not mentioned here. Unfortunately, these constructs don't always converge; they are similar to the SA construct (and to mental workload) in that there is little agreement among authors in how these theories streamline together, or in how they relate to each other. To choose one term such as "mental model," "schema," or "automaticity" to describe the "integration" element for a definition of SA would be extremely difficult; in addition, it would be poorly understood by those who are not familiar with information processing literature. Developing a definition of SA which is understood and accepted by the pilot and aerospace communities is important. Presenting this element in terms indicating the **integration of information into an overall mental picture** meets this criterion, and avoids selecting from the many specific cognitive constructs discussed above. Thus, this terminology will be employed here in a consolidated SA definition.

It's About Time

Along with the perceptual cycle and internal world model, there is one final concept not yet mentioned which is integral to any discussion of SA: the temporal dimension. Temporal awareness has been described as the most critical element in maintaining SA (e.g., Harwood, Barnett, and Wickens, 1988; Sarter and Woods, 1991). "Staying ahead of the airplane" is a phrase often used to summarize a pilot's ability to anticipate and prepare for future events (e.g. Regal, Rogers, and Boucek, 1988; Schwartz, 1993).

The timeline which characterizes a flight or a mission is relentless; after takeoff, the aircraft will move through space and time whether the crew are in pace with it or not. Like the operators of any complex and dynamic system, pilots constantly must think ahead to the next step, anticipating future actions and trends. One reason for this is that unforeseen occurrences and emergencies are inevitable, and if the crew are not thinking ahead of the timeline, they can easily become mired in a catch-up game which can create panic and a snowball of mistakes. In a non-attribution system for reporting unsafe conditions in-flight, pilots themselves report that a lack of temporal awareness frequently leads to unsafe situations, and that this aspect of piloting merits more study (Sarter and Woods, 1991).

As to how this temporal dimension should be included in an all-encompassing definition of SA, consider the definitions of Endsley (1990) and Carroll (1992). Endsley, as might be expected following the description of SA Levels 1 (perception) and 2 (a holistic picture of the environment) above, completes the breakdown with Level 3 SA, the ability to translate a pilot's mental model into projections of the future. Indeed, this concept forms the last phrase of her formal definition of SA (See Table 1). The definition from Carroll (1992) similarly concludes with "the ability to forecast, then execute tasks based on that perception." (p. 6) These perspectives are related to **anticipating,** thinking ahead of the aircraft, and predicting the implications of currently-known information. (The past, or gone-by segment of the timeline is also important in SA, insofar as it contributes to the pilot's current picture. Because it is inherent in the description of what makes up the mental model, it is not proposed for inclusion in a definition.) Because thinking ahead, forecasting, and projecting into the future are so important in the development and maintenance of superior SA, words to this effect should be included in a definition of SA.

Putting it together...

Up to this point, we have established four pieces of information which should be included in a comprehensive definition of SA. They are (1) extracting information from the environment; (2) integrating this information with relevant internal knowledge to create a mental picture of the current situation; and (3) using this picture to direct further exploration in a continual perceptual cycle, as well as to (4) anticipate future events.

Keeping these four points in mind while reviewing all of the existing definitions, the following definition is proposed:

> *Continuous extraction of environmental information, integration of this information with previous knowledge to form a coherent mental picture, and the use of that picture in directing further perception and anticipating future events.*

The **process** of SA includes extraction, integration, and the use of the mental picture, while the picture itself is the **product** SA. Thus, the product SA can be poor or good, depending upon whether the process is successful in putting together a picture which is accurate and complete.

Of all the definitions listed in Table 1, the one above is most similar to Endsley's (1990) and Carroll's (1992). Endsley's work describes perception as an active and cyclical process, but that distinction is not brought out in her definition. Carroll's definition is widely used in Air Force circles, but gives no mention to the integration of perceptual activity, which is a key factor. As a result, neither of these definitions was adopted here.

Conclusions

This paper is an attempt to describe the thought process involved in developing a definition of SA which reflects current thinking and which is void of psychological or military jargon. It is focused on pilot SA, but could easily be applied to operators of other complex

systems, such as air traffic controllers or nuclear power plant operators. It would be naive to expect SA researchers worldwide to read this, scratch their heads, and say "Hmm. Yes, this is it!" Nevertheless, for the reasons outlined in the introduction to this paper, it is important that an effort be made to combine the ideas of the many people working to define, study, and measure SA. We are a group in search of understanding, in search of SA, as to what to do about this concept which has taken the aviation community by storm.

Kantowitz and Casper (1988, p. 162), in a chapter on workload in aviation, state: "There is no empirical technique for proving a definition. Definitions are not correct or incorrect, but rather more or less useful. Ultimately, individuals must decide which definition of workload will be most helpful in accomplishing their own goals." I think these words can be well applied to SA as well. I apologize for the implication inherent in this paper that other definitions are not correct or useful. Many of these definitions, Endsley's in particular, have been used repeatedly by other researchers as highly useful standards. All definitions have been useful to those who have written them as a minimum in providing direction and understanding. As to where we go from here, there are many possibilities. Flach (1993) presents an exciting challenge to the human factors community to leave behind the approaches which were employed with mental workload. He suggests using SA as an opportunity to create a "theory of situations," a positive framework within which to study how humans perform in the context of specific complex and dynamic work environments. Pew (1994) also puts emphasis on understanding what is meant by the term "situation." Researchers at the RAF Institute for Aviation Medicine have long been forging ahead with quality research, considering SA as a global paradigm through which to study the pilot-vehicle interface (Taylor and Selcon, 1990). This work has bypassed the definitional debate, instead preferring to empirically determine the nature of SA (Taylor, 1990). Another interesting tact is studying the linkage between expertise and SA (see Crane, 1992; Flach, 1993; Sarter and Woods, 1991; and Tenney et al., 1992 for more on this subject).

Researchers in the field of SA stand on the brink of work which could have great impact on the future design of cockpits and training programs, not to mention man-machine interface of numerous other crew systems. A definition has been presented which hopefully can move us beyond one point of contention in the study of this interesting construct.

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COGNITIVE AND PERFORMANCE COMPONENTS OF SITUATION AWARENESS: SAINT Team Task One Report

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The present paper is intended to outline the relevant psychological issues for guiding situation awareness (SA) research in the Air Force. Specifically, it is an opening statement for guiding the initial research of the Armstrong Laboratory's Situation Awareness Integration (SAINT) team.

In order to produce the document in a timely fashion the literature review portion emphasized two sources of information: (a) combining information from the diverse members of the SAINT team itself; and (b) exploiting recent literature reviews on relevant topics. The SAINT team members represented a wide variety of backgrounds and research orientations. All members have active research projects on SA or related topics. While not completely exhaustive, the information from the SAINT team members was considered to be a solid cross-section of the current thinking regarding SA. This base was supplemented by using literature reviews of the vital areas. Most notably, CSERIAC has recently completed a State of the Art Review (SOAR) on the cognitive issues associated with operator strategies in managing workload in dynamic environments. The conceptual framework developed in this review has great relevance to SA research. As necessary, the primary sources identified as critical in (a) or (b) were directly accessed.

Definitional Issues

A precise and universally acceptable definition of anything is always difficult in science, especially at the beginning of a new research endeavor. Nevertheless, it is essential to constrain a concept somewhat before any cohesive research program can be outlined. As a starting point the SAINT team has decided to use the following definition suggested by Carroll (1992):

> ***Situation Awareness (SA)*** *- A pilot's continuous perception of self and aircraft in relation to the dynamic environment of flight, threats, and mission, and the capability to forecast, then execute tasks based on the perception.*

Two vital aspects of this definition need to be highlighted. First, despite the name, SA involves much more than just simple awareness of the situation. Good SA implies a capability to respond appropriately, not just the possession of an accurate assessment. It is conceivable that a person could be well aware of every aspect of the situation at the present point of time and still be incapable of acting adaptively. The term SA implies not only understanding the current disposition of actors within a situation but reasonable projections of future trends. This understanding is assumed to be necessary for the selection or creation of plans that will result in an operator achieving his/her goals. In psychological terms, this means that SA involves more

than perception or pattern recognition: it doubtless requires use of all the higher cognitive functions a person can bring to a task.

Second, despite the focus on the pilot and an aircraft, the basic approach to SA can be applied to operators of almost any type of system. This paper and much of the first-year research of the SAINT team will focus on the SA issues involved in a pilot engaged in visually guided air-to-air combat because this is one of the most challenging arenas for testing SA tools of any sort and it is the cutting-edge concern for the Air Force. However, we cannot afford to overlook the fact that SA is an element in other mission-critical jobs. The modern pilot is much more likely than before to be part of a real-time network of components trying to achieve air superiority. For example, the pilot will often be guided to a favorable situation by an AWACS weapons director. This AWACS weapons director will be using a very crowded display to guide the air-battle and it can be assumed that the enemy aircraft will be trying their best to confuse the AWACS weapons director. So, SA is a relevant topic to this operator as well. If the AWACS weapons director's SA is low, it may be impossible for the pilot to compensate.

The Psychology of SA in Air-to-Air Combat

The air-to-air combat arena is certainly among the most challenging SA environments that is engaged in by humans. The physical environment itself is a very difficult one, especially if high-G maneuvers are required. The relevant stimuli, usually visual, are often very weak and brief. The geometry relating all of the active participants can be very complex and rapidly changing. The motor demands of operating all of the myriad controls available to a pilot is a task requiring daunting precision. Furthermore, the task is performed for the highest stakes possible. Not only is the individual pilot's life possibly forfeit if performance is sub-par, but the lives of his or her colleagues and the mission goals are also at risk. All-in-all, it seems likely that any perceptual/ cognitive component might be important in such a demanding environment. But it is not helpful to say we should study everything, some selection is necessary. As a starting point, the psychological issues can be divided into two basic types: (1) perceptual-motor issues, and (2) cognitive issues.

Perceptual-Motor Issues

In this context, the term "perceptual-motor" is intended to connote, in a crude way, the relatively peripheral psychological processes used to get information into or out of the human operator. As a first cut, these processes include: sensory acuity, perception and pattern recognition, and motor control. Each of these will be discussed in turn.

Sensory Acuity. We can assume as a given that anyone selected as a potential Air Force pilot will not have notable deficiencies in their sensory capabilities. The question to be considered here is whether unusual sensory capabilities are to be desired as a means of improving operational SA.

The most obvious sense modality to consider is vision. Historically, the detection of enemy aircraft was done by sight and the first pilot to spot the other's aircraft had a huge

advantage. Used properly, this advantage was often translated into an approach and attack before the other pilot realized that a threat existed. It is estimated that 80% of air combat kills in World War I and World War II occurred without the victim realizing that they were under attack until their opponent opened fire (Spick, 1988).

Not surprisingly, many pilots of this era attribute some of their success to good eyesight. For example, Chuck Yeager points out that his 20/10 vision gave him a considerable edge in World War II (Sipe and Weksler, 1992). This has even been implemented as a feature in the air combat video game that bears his name. A player can activate "Yeagervision" and a 2x zoom allows him or her to see detail twice as far away as normal. Another anecdotal example would be Saburo Sakai's discussion of the leading World War II Japanese ace, Hiroshi Nishizawa; "Even his eyesight was unusual. Where we could only see sky, Nishizawa, with almost supernatural vision, could catch the specks of enemy planes still invisible to us." (Sakai, 1958, p. 84).

In the laboratory, there have been some intriguing correlations between visual capabilities and flight performance. For example, Kruk, Regan and Beverly (1983) found that various tests of super-threshold motion were correlated with several aspects of performance in a flight simulator. Most relevant to the present discussion, Kruk et al. (1983) detected a relationship between the ability to discriminate different rates of expansion of a test flow pattern and performance in a simulated bombing task.

Unfortunately, there is little evidence that simple visual acuity separates the ace from the regular pilot in the air-to-air arena. One could also argue that the current trends in air combat are likely to reduce the pilot's dependence on their own visual acuity. In the recent Gulf War, a large proportion of the sorties occurred at night. Much of the action was guided by radar information (either from the aircraft's own radar or from an AWACS aircraft), and the participants were often separated by distances that would have made vision difficult to use even in the daylight. For example, in a discussion of an air-to-air kill near Baghdad by Air Force pilot Captain Steve Tate, the formation is described with Tate's wingman being about 35 miles behind him, and the actual engagement with an Iraqi Mirage F-1 started at 16 miles with a radar lockup and "closed" to about 12 miles when he fired the Sparrow missile (Ewing, 1992). According to the story, the first visual look Captain Tate got of the Iraqi aircraft occurred when the Sparrow missile detonated at about 4 miles away, illuminating the pieces of the exploding aircraft. Unusual visual acuity obviously did not play a critical role in this engagement nor are the attributes of this mission unusual in light of current technology and tactics.

Nevertheless, with the current trend towards stealth aircraft, it would be presumptuous to assume that night-time radar engagements will always be the norm. It is not implausible to foresee missions that will require a pilot to use the basic eyeball as the principal search device. Therefore, visual acuity is probably a worthy consideration for evaluating a person's capability to maintain SA.

It is also worth noting that there may be a training aspect to visual acuity as applied to aviation. Chuck Yeager suggests that most people looking out of the cockpit will have a tendency to focus at about 18 feet. It was essential for a fighter pilot to learn to voluntarily focus

the eyes to infinity while searching the sky for enemies (Iverson, 1991). Spick (1988) cites ace George Buerling as another example of this. Buerling would practice flicking his eyes around a room and focusing on objects at different distances quickly, "so that when you look around the sky once, you pick up anything that's out there" (p. 117).

Perception and Pattern Recognition. It is often difficult in practice to cleanly distinguish between sensory processing and perceptual processing since even the most peripheral sensory processing is influenced by meaningful patterns. However, at this level of the discussion we will focus on processing that is involved with the preliminary assignment of stimulus meaning.

Quickly "sizing-up" a situation seems like a very adaptive trait for a fighter pilot. Rereading the above quote about Nishizawa, the emphasis could be placed on near-threshold perceptual processing rather than visual acuity. Stories of exceptional pilots having an intuitive feel for the geometry of an air battle going on around them are especially common for World War I aces (Spick, 1988).

Of a more scientific nature, Youngling, Levine, Mocharnuk, and Weston (1977) noted that one of the selection tests used in World War II was the hidden figure detection test and this test had one of the highest correlations with training program survival.

More recently, verbal protocol evaluations have been conducted to compare novice and expert Air Force pilots conducting simulated air intercepts (Blackman, Sullivan, and Seidler, in preparation; Sullivan and Blackman, 1991). Among the findings of this research is that expert pilots tend to attend more to the overall geometry relating all players, while novices will tend to focus on a single opponent to engage. In other words, the perception of the situation, as indicated by verbal protocols, tend to imply that novices and experts perceive the situation differently. As structured in the above experiments, this difference in perception would appear to be the result of training. However, it is certainly plausible that people differ in their abilities to make the transition to perceiving the more complex geometry.

Overall, the speed and accuracy of the pilot's perceptual processes (especially those involved in detecting complex geometrical relationships) are likely to be critical components in the acquisition and maintenance of pilot SA.

Motor Control. Flying an aircraft well requires good motor control. Maintaining a good flight path often requires precise tracking behavior. A pilot attempting to shoot down another aircraft with a gun is involved in a tracking task that requires exceptional precision. This task might become rare in the future, though. In the Gulf War there were only two air-to-air kills using a gun. Both were A-10 aircraft shooting down helicopters with their 30 mm cannon. Missiles are starting to live up to their potential and air-to-air shooting is likely to diminish. On the increase however, is the switchology associated with using the complex displays and automated subsystems that are becoming more and more common in modern aircraft.

This increasing complexity means that motor control could be an important issue for selection and training, but it is not clear how this could be directly related to SA. It would be

unwise, however, to overlook the possibility of an indirect connection between motor control abilities and SA. It is conceivable that pilots with better motor control abilities require less attention allocated to the rudiments of flying the aircraft and controlling the switches. This might reduce the potential for distracting the pilot away from maintaining SA.

Cognitive Issues

Cognitive issues refer to the more central information processing issues associated with SA. These seem likely to be more important than the peripheral processes. In fact, a recent review on SA by Hartman and Secrist (1991) concludes that, "situational awareness is principally in the cognitive domain" (p. 1089). Unfortunately, the relevant issues in the cognitive domain are very difficult to categorize.

One of the main difficulties in understanding the cognitive issues associated with piloting an aircraft involved in air-to-air combat is the complexity of the environment itself. Air-to-air engagements occur within a longer mission. Numerous goals and criteria may influence a pilot's decision-making at any point in time (e.g., reaching a target, defending yourself, monitoring aircraft status, fuel management, etc.). Accomplishing any goal might involve multiple tasks (e.g., maneuvering the aircraft while selecting a weapon's mode to initiate an attack). Furthermore, any representation of the task environment is likely to be very complex. Consider that in order to build a three-dimensional representation of the battle, the pilot must obtain information from a two-dimensional flat radar screen. The range and azimuth information is usually presented in a spatial format on the screen, with some associated information (e.g., altitude, closure rate) presented digitally. The pilot will also communicate via the radio with his wingman, and must correlate the wingman's interpretation of the situation with his own. Further communications may occur with either a Ground Controller and/or an AWACS controller All of these diverse forms of information must be combined into a composite understanding of the situation that will guide action against a threat that is actively trying to confuse and attack the pilot. In many scenarios, all of this processing is occurring while the pilot and his potential enemy are closing at rates of about 20 nm per minute.

The cognitive abilities a human operator brings to performing these complex tasks are notable for their seemingly severe limitations. Attention seems to suffer when divided over even two fairly simple tasks, and short-term memory has a well-known and seemingly quite fixed capacity of 7 plus or minus 2 items. Human operators seem to be poorly suited for multi-task environments, yet they perform in them regularly. How can this be?

Hartman and Secrist (1991) emphasize three phenomena that they believe are essential to creating and maintaining SA in the complex air combat arena: (1) Automaticity, (2) Near-Threshold Processing, and (3) Skilled Memory. Automaticity refers to the fast, seemingly effortless processing that produces performance in some well-trained tasks. Developing automaticity is primarily a result of producing a training regime that emphasizes the consistent components available in a task environment, and then overlearning the detection of and response to these consistent events. However, Schneider (1985) cautions that this has implications for selection. Schneider points out that initial performance in a consistent component skill is only

weakly correlated to final performance on that same skill. This implies that any selection that is to be done on components that will automatized by the training should be done following some training.

Hartman and Secrist (1991, p. 1087) define the role of near-threshold processing as follows: "The essence of near-threshold processing is that individuals can acquire, analyze, process, and be affected by sensory stimuli below the level of conscious awareness and that cognitive and decision processes can be modified as a result." Clearly, an ability or skill to do this sort of processing would greatly alleviate the demands on the very limited conscious processing available to pilots. At the moment, it remains to be determined whether this is more usefully conceptualized as an ability that should be measured in the course of selection, or as a general skill that can be trained in the student pilot population, or as some combination of the two.

Finally, Hartman and Secrist (1991) identify skilled memory as a major contributor to SA. This is consistent with another current review of cognitive issues in complex task performance by Adams, Tenney, and Pew (1991). Adams et al. (1991) offer a careful analysis of the means by which a human operator overcomes information processing limits on attention and memory to perform adaptively in complex multi-task environments. Many of the issues discussed are beyond the scope of the present paper, but the main thrust is that developing expertise is the method that operators use to overcome the limits of their cognitive systems. Expertise aids attentional allocation in that attention will be directed to the information source that is relevant to the currently most important goal. Expertise aids memory in an even more dramatic fashion. Little can be done to change the 7 plus or minus 2 limit on STM, but with training the use of memory itself becomes skilled. Skilled memory has been extensively studied by a group of researchers at Carnegie-Mellon University (e.g., Ericsson and Straszewski, 1989). Skilled memory theory postulates three principles: The *Meaningful Encoding Principle* states that experts durably encode task-relevant information. The *Retrieval Structure Principle* states that experts possess memory structures to support the facile retrieval of task-relevant information. Finally, the *Speed-up Principle* states that with practice the information processing associated with a task is performed more quickly and efficiently. The overall effect of skilled memory is that an individual who possesses or has developed skilled memory in a domain appears to have a functionally expanded memory through the efficient exchange of information from STM to LTM. This will produce impressive performance within the domain but will transfer poorly, if at all, to any other domain.

The fact that such expertise appears to be domain-specific presents a challenge for personnel selection. Is there anyway to select individuals that are especially prone to developing effective skilled memory? No evidence either way exists. Thus, tests of basic memory abilities should be examined for their relevance to the creation of skilled memory and new tests aimed at examining the development of skilled memory in a simple domain might be considered.

The tenets of skilled memory theory also agree with another general trend in decision making research. Klein (1989; Klein and Klinger, 1991) has suggested that the traditional theories of decision making proposed a level of information processing that was far too demanding to be adaptive in naturalistic real-time environments. As an alternative, he suggests an

approach based on a Recognition-Primed Decision Model. In this approach the operator's expertise allows the operator to classify the task as an example of some familiar category. This classification will serve to provide such things as goals, information to seek or monitor, and courses of action. This predisposition to act according to previous experience (with suitable modification) reduces the computational demands greatly as opposed to generating and evaluating a large selection of options. Such a strategy is consistent with meaningful encoding activating a course of action from a domain specific retrieval structure. However, Klein's viewpoint suggests that the main work done in real-time decision-making may be perceptual in nature, thus suggesting that perceptual tests might be an important selection tool. There is no evidence to support this conjecture at the moment, but it is empirically testable.

On the other hand, Adams et al. (1991) point out that there does seem to be evidence that individuals can be categorized according to the effectiveness of their attentional allocation. For example, in a test of Israeli flight cadets, the selective attention capabilities as measured by a dichotic listening test were significantly better for successful flight cadets than for those that ultimately failed (Gopher, 1982). Furthermore, performance on this test was not completely correlated with performance on other tests in the selection battery, indicating that the test tapped an ability that had previously not been measured. In an independent evaluation the test was used to measure the attentional capabilities of professional bus drivers (Kahneman, Ben-Ishai, and Lotan, 1973). Performance on the test was significantly correlated with the drivers' accident rate. This implies that the attentional capabilities remain a limiting factor in performance at even high levels of expertise.

There is an interesting contrast between this apparent stability of attentional capabilities observed in the above studies and some research regarding the training of attentional control as a psychological skill. Gopher and his colleagues (Gopher, 1993; Gopher, Weil, Bareket, and Caspi, 1988; Gopher, Weil, and Seigel, 1989) have demonstrated that using a complex video game with a training program that emphasizes developing attentional control skills has a dramatic effect on performance in flight training. Israeli Air Force cadets that received the "Space Fortress" video game attention training program had only half the attrition from flight training a year and a half later. The video game training has become a part of the Israeli Air Force training program. Hart and Battiste (1992) replicated the efficacy of the program in a similar evaluation conducted with US Army Helicopter trainees at Fort Rucker, Alabama. Not only did Hart and Battiste find that the "Space Fortress" training aided flight school performance relative to trainees with no video game experience, but they compared the effect of "Space Fortress" training to the effect of a placebo control using a commercial video game ("Apache Strike"). The "Space Fortress" group outperformed both the no-game group and the "Apache-Strike" group. This suggests that the observed effects are neither a placebo effect nor an outcome of just any video game experience. Instead, the results suggest that attentional control is a learnable skill. It would be useful to determine whether the "Space Fortress" effect altered people's performance in the dichotic attention test described above. Whether this time-sharing effect turns out to be an ability or a trainable skill may be less important than the more general implication that such time-sharing phenomena are potentially an important part of creating and maintaining SA. Therefore, attentional control might be considered a fourth key cognitive issue to be considered along with the three suggested by Hartman and Secrist (1991).

A final concern that is not normally considered "cognitive," but fits here as well as anywhere, is the stress resistance of the pilots. High information loads alone can be considered stressors. When these information loads are combined with the challenging physical demands of flying a high performance aircraft, and the risks to oneself and others, the resulting environment is fraught with potential stress. Youngling et al. (1977) conclude that reactions to stress and emotional control are an important aspect separating aces from average combat pilots. At first consideration it might be difficult to see any relation between this and SA. However, work in sports psychology aimed at reducing adverse athlete reactions to stress tend to utilize attentional control training, typically combining imagery and relaxation training (Martens, 1987). Oddly, when imagery-based techniques have been studied in Air Force settings, the focus has been on their potential motor learning effects not the potential attentional and stress control benefits (e.g., Prather, 1973). Again, research is needed to distinguish between stress resistance and emotional control as an individual trait or a trainable skill. In either case, strong reaction to stress or lack of emotional control is likely to disrupt attempts to maintain SA.

Implications

Implications of the above discussion of SA fall into three broad categories: selection, training, and measurement. Each of these will be discussed in turn, but it is important to keep in mind that in practice it would be unwise to try to study these issues in isolation from each other since they would be strongly inter-related.

Selection of individuals that possess abilities beneficial to SA certainly makes sense if it can be accomplished. On the basis of the above discussion it seems likely that selection tests of the perceptual-motor capabilities are the most straightforward selection contribution. Tests of visual acuity and control of depth of focus might be a start. However, if the current trend toward Beyond-Visual-Range engagements continues, it is difficult to see much of a contribution from this type of testing. Therefore, the bigger payoff might be in tests of perceptual function (i.e., speed and accuracy of perception, ability to utilize near-threshold information, integration of multiple sources of information into one controlled response, etc.). Not only do such perceptual tests have good face validity for their value in human performance, but the discussion of recognition-primed decision making suggests that basic perceptual functioning may play a vital role in what was traditionally thought to be the domain of higher cognitive functioning. Within cognitive processing itself, it would be advisable to test the speed, accuracy, and capacity for dealing with cognitive processing within different formats or codes. Many of the pilot's displays present spatial representations of the situation and the verbal protocol data discussed above implies that such representations are an important portion of the expert pilot's thought processes. Therefore, tests of the potential pilot's spatial processing or imagery abilities might be appropriate. However, whatever spatial model the pilot might be maintaining to perform the task will have to be supplemented by verbal information from other pilots or controllers, so testing verbal abilities and capacities also makes sense. Tests of attentional control might also predict the ability to cope with complex dynamic environments. The two topics discussed above that might prove prohibitively difficult to implement in a traditional selection battery would be the adequacy of the individual's domain-specific skilled memory. Since all three principle's of skilled memory require

extensive domain-specific training to develop, they can only be tested well into the training program. This is not attractive from a selection point of view. Also, within the ethics that prevail in the normal testing environment, it is unlikely that a compelling manipulation of the sort of stress faced in the real-world task will be achievable.

A preliminary battery of potential selection tests is presented in Table 1. These tasks represent a subset of the tasks used in the Basic Attributes Tests (BAT) system (Carretta, 1987) and others developed in the Air Force's Learning Abilities Measurement Program (LAMP). The tests were selected to cover the wide variety of abilities covered in the present paper with at least

TABLE 1.

Proposed Battery of Selection Tests

Test Name		Attribute Tested
TP-S1 TP-S2 Anticipation	➡	Temporal Processing
WMV2 WMV4	➡	Verbal Working Memory
WMS1 WMS3	➡	Spatial Working Memory
Manikin Water Tower	➡	Spatial Orientation
Shepard/Metzler Pitch/Roll/Yaw	➡	Spatial Visualization
Mental Rotation CAM1 Fig Mat	➡	Spatial Relationships
Inst Comp Matrices	➡	Spatial Reasoning
Scan & Allocate Time-Share 2	➡	Time-Sharing
Laser Shoot 1 Laser Shoot 2 Complex Coordination	➡	Psychomotor
Hartman	➡	Near-Threshold Processing
Scheduling 2 Dichotic Listening	➡	Attentional Control
Space Fortress	➡	Complex Attentional Control

two tests for any individual abilities. The redundancy of tests for the different abilities is essential to ensure accurate interpretation of the results. In addition to the more traditional selection tests the proposed battery includes a near-threshold processing test developed by Bryce Hartman and the Space Fortress task. Inclusion of these tests was encouraged by the previous results and analyses reviewed above.

Training issues complement the discussion of selection issues. In several of the topics above, it was unclear whether an attribute (e.g., control of depth perception, or attentional control) was a fixed ability or a trainable generic psychological skill. Training with a task like the "Space Fortress" game is too time consuming (about 10 hours) to fit within the framework of the traditional task battery. However, if such training can compensate for attentional control deficiencies that might show up as a result of selection testing (perhaps with the dichotic listening test), then a bad attentional control score might not have to be a basis for rejecting someone from a training program.

Finally, any research in an area requires the ability to measure outcome. Fundamental research in generic approaches to measuring SA has been underway for several years, and progress has been made. However, a generic SA measurement instrument is prone to the same limitation discussed above with selection tools. Generic measurements will be ill-suited for measuring the domain-specific aspects of a person's expertise. A potential way to compensate for this is to develop domain-specific measurement tools. In the air-to-air combat domain a viable strategy is to use experts to evaluate the performance of trainees. Instructor ratings have a long history of value in classifying student capabilities (Youngling et al., 1977). The expert raters could conceivably try to rate all of the dimensions discussed above. But, given that selection tests will probably be well-suited for assessing the perceptual-motor aspects discussed above, the biggest payoff for the expert ratings might be in the area of domain-specific knowledge for which it is so difficult to develop a selection test. To do this properly, we need tools to extract and represent the expert's knowledge about performing a mission. This representation can then be used to specify the dimensions of a rating scale to be used by experts observing a students performance. Progress in this direction has already started: Houck and his colleagues (Houck, Whitaker, and Kendall, 1991, 1992) have created a behavioral taxonomy for air-to-air combat in F-15s. The taxonomy is based on mission and cognitive task analyses of the defensive counter-air missions flown by F-15 pilots. On the basis of extensive interviews of F-15 pilots, Houck et al. (1991, 1992) identified the critical activities, decisions, and information requirements of the mission. Elements of this taxonomy should make an excellent starting point for developing a specific observational rating tool for evaluating the performance of pilots in a air combat simulation. The end result should be a reliable quantification tool for assessing a trainee's current state of knowledge within a task domain. These ratings can then be used as dependent measures in whatever evaluation might be conducted or as an aid for making a training program adaptive to a trainee's needs. Given the ability to put the trainee in a stressful environment, expert evaluation might be one of the most efficient ways to examine the trainee's grace under pressure.

Consequently, we can conclude that the most effective way to make progress in any of these domains (selection, training, and measurement) is to begin a coordinated program that examines all three issues and the relationships between them.

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SA: An Operational Point of View

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In the 1970s, crewmembers attending C-130 (i.e., the Lockheed C-130 Hercules transport aircraft or "Herk") upgrade training at Little Rock Air Force Base, Arkansas were shown a film entitled "Anything, Anywhere, Anytime" (1971, AFCVIL Film #20981, Norton AFB). The film, describing the special ability of Herk crews to deliver "anything" (personnel, a variety of cargo) "anywhere" (worldwide, using airdrop or airland methods) at "anytime" (around the clock, during war or peace), featured the conflict in Southeast Asia and focused on the battle of Khe Sanh. The viewing served as an "attention getter" and motivator for students.

The film's contents also bring to mind several important aspects of Situational Awareness (SA). First, a pilot (or other crewmember) who possesses good SA will strive to maintain it -- in order to handle "anything" (task, threat, problem, etc.), "anywhere" (scenarios, locations), and at "anytime" (time here can be thought of in the sense of 24 hours or present/future). Secondly, the crew concept stressed in the film highlights the fact that crewmembers play different roles in accomplishing a mission and, in doing so, contribute to the overall crew or team SA.

The following discussion of SA has more of an operational than scientific flavor. Airplane "drivers" and those investigating the scientific aspects of SA can benefit from exposure to each other's concerns and areas of emphasis. SA will not be defined nor will cognitive aspects be discussed in detail; those topics are covered separately in this tech report. The first section of this paper will comment on the direction of current SA research. Next, an operator's thoughts on the major factors that contribute to good SA will be presented. Finally, through a description of a tactical airdrop scenario, a broader view of SA - featuring CRM (Cockpit or Crew Resource Management) - will be presented.

Current Research - A Commentary

Much of the literature on SA is found in two main categories of publications: scientific journals and papers, and operational type flying magazines. This tech report falls into the first group. A quick reading of the keywords reveals that current scientific writing on SA focuses on the following areas: definition, measures, workload, and modeling. Furthermore, when focusing on flight operations, most SA studies feature air-to-air or air combat maneuver (ACM) scenarios.

The second source of SA literature is the series of "trade" or operational reviews, such as the *Mac Flyer* (now the *Mobility Forum* of Air Mobility Command), *TAC Attack* (now *Combat Edge*of Air Combat Command) of the USAF, *Approach* of the U.S. Navy, and *Airline Pilot* of the Air Line Pilots Association. SA-related articles found in these types of publications are characterized by: (1) an emphasis on safety; (2) constant stress on cockpit-, procedural-, and self-discipline; and (3) in the case of transport aircraft, a highlighting of the importance of Cockpit/Crew Resource Management.

The primary differences between these two groups of SA literature are as follows. Scientific articles normally focus on a specific aspect of SA, while operational type reviews tend to take a broader point of view. Authors of scientific articles normally make their points by means of experiments and studies; operational articles make use of accident report summaries (case studies) or "attaboys" (citations for commendable performance during incidents) to educate and/or train. Finally, many scientific articles define SA in the text; operational articles often talk about the concept without defining it. (The lack of an SA definition in the second group may follow from an assumption that the flying community has a general understanding of SA. Air Force Manual 51-37, the "bible" of instrument flying for Air Force pilots, does not define SA, even though good SA is critical to instrument flying.)

From a strictly operational point of view, SA is most often viewed as a broad concept, or state (similar, perhaps, to the "gestalt" of some scientific/research literature). Therefore, the narrow focus of a scientific study, by its specificity, may be a limitation. Furthermore, that which is measured may only be a symptom, result, or projection of SA, but not a true measure of overall operational SA. This may be the case in a memory probe, for example. Of course, this does not mean that scientific or laboratory studies of SA are of no value; in fact, new discoveries concerning specific aspects of SA abilities might aid future "fine tuning" of operational expertise and both individual and team SA capacity.

Is it possible to determine if a crewmember (or crew "team") has a good SA without defining the concept and without "measuring" it? Yes, indirectly. At one end of an SA "scale," basic survival (meaning aircrew, wingmen and, if applicable, passengers alive; aircraft intact) is an indicator of at least minimally sufficient SA, for RTB ("return to base" in pilot lingo) has been accomplished and all will fly again. Include threats, mechanical problems, weather, unforeseen circumstances, etc., and that sufficiency of SA may now be considered at least good SA, because that crew's SA has been challenged and successfully exercised to overcome problematic situations. Now, consider those types of problems (or challenges to SA) just described, but add mission accomplishment, be it bombs on target, air supremacy established, ground support attained, or cargo/passengers delivered. That crew which is aware of -- and copes with -- all situations, while not only surviving but accomplishing the mission, is operating in the realm of excellence at the high end of the SA "scale."

In July, 1989, a United Airlines DC-10 crashed at Sioux Falls, Iowa. Although 111 persons died, this accident serves as an excellent example of SA at the high end of the scale just described. The initial "mission" was simply to transport passengers from Denver to Chicago; however, when catastrophic failure of the flight controls occurred (caused by a separated engine fan disc severing hydraulic lines), the mission immediately changed to one of simply gaining control of the airplane and landing as soon as possible while minimizing deaths. Thanks to superb SA and CRM (including outstanding assistance from a deadheading crewmember, air traffic controllers, and ground emergency response teams), 174 passengers survived in what could have been total disaster.

A "time" element of SA is often mentioned in scientific definitions in terms of a pilot's ability to "project" a solution. (See definitions of Endsley; Harwood, Barnett, & Wickens; and

Schwartz in the Bibliography section of this report.) Beginning with "day one" of Undergraduate Pilot Training, operators speak of "keeping ahead of the airplane." This operational concept of time may be broken into three divisions as a technique for staying aware and ahead; the present, the near future, and the future (longer term). The "present" SA consists, as a minimum, of the basics of position, attitude, altitude, speed, configuration, maintenance status, and environmental threat. The near future may vary in time from immediately to several minutes (or even longer), depending on the situation and the threats or challenges: "What am I going to do next with my machine?" The future can be thought of as a realm where the situation for which the pilot/crew is mentally, or even physically, planning and preparing (rigging for an airdrop, arming weapons, etc.) but which is not of immediate concern. This activity could be an approach, landing, bomb drop, air drop, or passage through a threat area. Of course, these artificial divisions of time are fluid in nature. (For another example of SA zones of interest, see Endsley, 1988b, listed in the Bibliography section.)

What Contributes to Good SA?

Many factors contribute to a pilot's or crew's SA. Because SA is so complex, some factors cannot be quantified. Those factors to be discussed here -- grouped into experience, personality, and mental/physical categories -- are not completely dependent on superior mental skills. Nevertheless, they play major roles in determining the quality of SA.

Experience. Experience factors which influence SA include knowledge, technical skills and preparation. Obviously, the more knowledge a pilot has concerning his/her aircraft, weapons systems, the enemy (specific threat, tactics, capabilities, offensive/defensive maneuvers), weather, etc., the more likely he/she will be able to properly assess a given situation. Improved technical skills -- from basic "stick and rudder" abilities to advanced offensive/defensive maneuvers -- resulting from training and experience (and, of course, a degree of natural ability) ease mental workload, allowing for improved situational awareness and analysis. In the United Airlines accident previously cited, experience and technical skills (the captain had been with United for 33 years; the deadheading captain was a check airman) were critical factors in averting a total disaster. Finally, basic mission preparation, including such items as threat analysis, weather, intelligence and route/target study, covers foreseeable problem situations and goes a long way towards improving SA and contributing to the efficient handling of unforeseen situations.

While performing a flight evaluation of an Air Force C-21 (Learjet) crew, the author observed a young pilot, a candidate for aircraft commander upgrade, fail a basic test of SA while on approach to the busy Los Angeles International Airport. This pilot, who had "golden hands" (excellent "stick and rudder" skills) and good technical knowledge, was cleared for a profile descent (a specific routing for descent and arrival to an airport) by air traffic control. Initially, he had no knowledge of the procedure. Greater experience and good mission preparation habits would not only have shown him where the procedure was published, he would have anticipated ("keeping ahead of the airplane") the clearance. In this case, fortunately, the result was embarrassment, not a life or death situation.

Personality. Several key personality factors influence the quality of an individual's SA. The pilot who possesses above average self-discipline is more likely to be "in the books" and have a more professional attitude towards flying tasks. The pilot who exhibits good attentiveness and alertness (to radios, maintenance, and weather, for example), as well as a healthy questioning or inquisitiveness (not to be confused with worrying) is working on excellent SA. Finally, the pilot who is always thinking ahead, formulating possible scenarios/situations -- and planning how to deal with them -- is well on his/her way to having superior SA.

Two individuals from the author's last flying unit of assignment stand out as pilots possessing the qualities just described -- as well as outstanding SA. Neither was satisfied with basic mission knowledge; in addition to intimate knowledge of AF regulations, flying procedures, aircraft systems, and FAA regulations, they constantly questioned the "how's" and "why's" of flying, during flight and while in the office. While on his first mission in the unit, during an extended descent to final approach, one of the pilots just described asked the instructor pilot who was flying: "What are you thinking about?" This train of thought -- quite different from the common questions pertaining to systems and procedures -- displayed a rare level of analysis, inquisitiveness and alertness.

Mental/Physical Factors. There are also several mental/physical factors which are related to the quality of a pilot's SA. For example, fatigue (such as chronic or acute fatigue, circadian dysrhythmia, etc.) and stress (from combat, personal problems, temperature, discomfort, etc.) will affect, as a minimum, alertness and attentiveness, key contributors to good SA. Drugs and alcohol should not be a factor -- if regulations are followed. However, crewmembers can follow regulations to the "T" but still be affected by alcohol consumption, either by short-term (hangover) or long-term (alcoholism) effects. Furthermore, self-medication, while forbidden, does take place, and the side affects (dehydration, drowsiness, nausea, disequilibrium, blurred vision) of over-the-counter medication can decrease SA.

Focus on Crew

In the operational world, there is one or more key group factors influencing the quality of SA, in this case playing an important role with crews, versus individual crewmembers. These factors are also the basis for Crew Resource Management (CRM): communicative ability, interpersonal skills, and leadership. Although only the pilot manipulates the flight controls, each individual crewmember's SA in his/her specialty (navigator, flight engineer, loadmaster, boom operator, weapons system operator, etc.) is dependent upon inputs from other crewmembers. Although the "C" in CRM serves as an abbreviation for "cockpit" or "crew," depending on the literature, this author prefers "crew." (This concept of crew effort will be discussed shortly in the description of a tactical airdrop mission.) In fact, there is an overall crew (team) SA greater than each individual crewmember's knowledge of his/her specialized SA.

Interpersonal skills play an important, albeit indirect, role in determining crew SA. A lack of skills in this area restricts the flow of information, spirit of cooperation, and attention to mission task necessary for high level SA and successful mission accomplishment. A crew with

interpersonal problems may function under routine tasking, but will be more likely to fail when stressed, subsequent communications falter, and SA, therefore, is reduced.

Leadership is the third key area of CRM which influences a crew's (and individual specialty) SA. Although the "M" in CRM refers to management, in fact, proper overall CRM -- particularly during non-standard operations -- requires leadership. Leadership can vary in style. It can be exercised by all crewmembers, depending on the task or phase of flight, with certain areas of responsibility -- and the overall safe conduct and direction of the mission -- reserved for the designated Flight Leader or Aircraft Commander (AC). (This position would be the Captain or Pilot in Command in the civilian world of the FAA.) Here, on a crew scale, the leadership factor -- and the AC's direction -- play a critical role in attention and focus. Just as the pilot of a single seat aircraft must be cognizant of many items making up SA while dealing with that item which is currently critical, so too must the AC, through an overall "big picture" of SA, monitor the focus of the crew and properly orchestrate the timing, attention, and direction of a crew.

In summary, good SA flows naturally from good CRM. A crew without proper CRM may safely accomplish a routine mission. Nevertheless, when "pressed to test," that same crew stands a good chance of failure due to incomplete SA.

SA in a Tactical Airdrop Mission

The idea of "anything, anywhere, anytime" as the basis for good SA was described in the beginning of this paper. Operational aspects of SA were then discussed. These two ideas will be combined in the setting of an operational mission which could involve delivering anything anywhere at anytime: a C-130 airdrop.

Although most discussions of SA center on fighter activities, the transport world provides a good example of how SA works, especially as related to CRM. A C-130 crew flying a low level mission to an airdrop may not be operating in the intense domain of the "fast movers"; nevertheless, there are elements of SA which parallel those experienced by the fighter pilot. The low level Herk mission can be every bit as intense and merits analysis and scrutiny on a par with that focused on the fighter community.

There are really three different levels of SA in a tactical formation of C-130s. First, each individual crewmember has his/her own area of expertise, awareness, and concentration, with some areas overlapping. The loadmaster's SA, for example, is largely focused on the activity in the back of the aircraft, such as security of the load and accomplishment of checklists. He may not be concerned with the winds over the drop zone (as long as they are not out of limits, which would necessitate a "no-drop" decision and subsequent actions and checklists), but the navigator and pilots certainly are. The navigator has an assigned responsibility concerning warnings at certain times, yet all crewmembers share a common time-related element of SA -- checklist accomplishment.

A second level of SA exists for the aircrew as a whole. This concept was previously covered under the discussion of CRM. (As mentioned before, this author interprets the "C" as

Crew.) The loadmaster, crew chief, drop zone controllers, and weather personnel are not in the cockpit, but they all play a critical role in mission accomplishment. The AC bears the major responsibility for maintenance of crew SA.

A third level, or "ring" of SA exists for the formation as a whole. The formation lead crew (basically the pilot and navigator) must maintain an awareness of the general integrity of the group, mission progress, and status of each aircraft and load. Certainly, each individual crew is aware of their own aircraft status, but the leader must maintain the "big picture."

From the very beginning of a tactical airlift mission, SA-related crew factors play a part in determining success. Even as a commander or an operations officer approves the schedule of a crew and mission, he/she must consider many of the factors cited as contributors to SA (experience, personality, CRM leadership, etc.) in order to bring balance to the crew and to ensure a safe flight and accurate drop. It is common practice that weaker crewmembers are teamed with crews containing stronger fellow crewmen.

Planning for missions can begin as much as weeks before the actual flight (in the case of a crisis or exercise) or as late as several hours before the airdrop (routine training). During this phase, those planning the mission (usually the more experienced navigators and pilots) must weigh the various factors of weather (wind, visibility, ceiling), loads (weight limits, drop zone conditions, drop altitudes), and enemy (real or simulated) location and threat, among others. The key to success here is judgment, brought about by experience.

During the briefing phase, most crewmembers (flight engineers and loadmasters are preparing the airplane and load) are together. Here is an extremely important opportunity for establishing the baseline of individual, team, and formation SA. The information, procedures, and instructions presented are critical to SA. As stated earlier, mission preparation plays a large role in superior SA.

During the flight, the main focus of each crewmember's SA is as follows. The aircraft commander concentrates on flying the airplane and, if serving as formation lead, on guiding/ monitoring all aircraft in the group. The copilot is responsible for general checklist accomplishment, navigation (shared with the navigator), and generally backing up the pilot on the flight controls. The navigator is largely responsible for directing the pilots to keep the aircraft on course and on time. He is also the key player who determines precisely where the load should be released. The flight engineer, seated between the pilots, monitors the maintenance status of the aircraft and "runs" (reads, ensuring proper and timely responses) the drop checklists. The loadmaster loads the aircraft, monitors the load (equipment or paratroopers) for safety and security during the route, and operates doors and ensures safe exit of the load during the drop. Although the individual areas of expertise and focus have just been described, the importance of the overlapping duties and the backing up of each other -- key aspects of the CRM concept -- cannot be overemphasized.

In the intense environment of air combat, the pilot of a single seat fighter is faced with a complex array of factors in maintaining proper SA. During an airdrop mission, a tactical airlift

pilot must also monitor and balance much information in order to maintain good SA. Of course, there are the basics of speed, altitude, attitude, position (in formation), location in relation to planned track as well as specific geographic coordinates (largely a navigator responsibility), fuel, and maintenance status (generally aided by the flight engineer). Secondly, there are items related to safety and security, such as types and locations of threats, defensive maneuvers, weather, and terrain. The SA of these factors is greatly aided by preflight preparation, mission planning, and -- en route -- good CRM. Finally, keeping in mind the ultimate goal of accurately dropping a load on target on time, the following must be considered for proper SA: time (status in relation to preplanned time over checkpoints, completion of drop checklists), winds (maintaining course, adjusting load release point), computing alternate plan (what if winds are out of limit? ... if a member of the formation doesn't drop? ...if maintenance problems or enemy fire disables an aircraft?). Fortunately, being a crew aircraft, all crewmembers contribute to the team SA.

Experience was previously discussed as a major enhancer of SA. This scenario provides an excellent example of how this quality becomes so important at a critical point during the mission. Proper position over the drop zone is paramount to a successful drop; exact alignment en route does not make a difference if the aircraft is off course and the load lands off the drop zone. The alignment and position of the lead aircraft is critical; this is when the prior experience of the pilot and navigator in sensing groundspeed, wind, and drift by feel, by smoke on the ground, or by the "seat of the pants" can lead to a successful drop, regardless of what the pre-computed air release point was calculated to be. After the drop, aircraft doors are closed, the formation "escapes" from the drop zone, and post-drop checklists are accomplished. In an actual conflict, when a drop is made to friendly troops in enemy territory, the formation must once again transit the area at low level while avoiding and evading threats.

Unfortunately, CRM and SA do fail, with a variety of consequences. A flight engineer forgets a step in a Container Delivery System checklist, the flaps are not reset for the proper angle for load release, and the drop is long. This instance was not only a mistake on the part of the flight engineer; crew SA (primarily pilot: "What configuration is the airplane in?") and CRM (other crewmembers, particularly the copilot, backing up the flight engineer on checklist accomplishment) have failed. A pilot concentrates on the runway during a night approach to a short field landing and allows the airspeed to decay -- his SA fails. Unfortunately, the aircraft stalls and crashes: team SA and CRM fail and two crewmembers die. Finally, a crew fails to challenge (CRM breakdown) an aircraft commander (experienced C-130 pilot, airline captain, and squadron commander designee) who decides to fly low level on the spur of the moment. Operating in a partial SA "vacuum" (no previous briefing, no route study, no low level charts on board), the aircraft clips a power line and all perish.

Conclusion

As previously noted, many pilot-oriented SA studies concentrate on fighter operations. However, the world of transport aircraft, both military and civilian, also presents many opportunities for studies in the areas of individual SA, team SA, and workload. Both fighter pilots and transport crews incorporate many of the same elements of SA, but in different settings. A challenged crew can provide a wealth of SA information.

Improved understanding of Situational Awareness is important to both the scientific community studying SA components as well as the operators flying aircraft. The focus of experiments and studies, when contrasted to the major operational factors influencing Situational Awareness, approaches SA from a different point of view. Nevertheless, the common objective of mission success with safety can be more readily attained by a mutual appreciation of each group's work and focus.

Report of the Armstrong Laboratory Situation Awareness Integration (SAINT) Team (Briefing Transcript)

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Background

The present study was initiated by a memo from the Chief of Staff of the Air Force. Figure 1 shows that memo from General McPeak. The Armstrong Laboratory's Situation Awareness Integration (or "SAINT") team was tasked to respond to General McPeak's concerns. Lt Col James Bushman and I served as program managers. When the team reviewed the memo, we felt that he was asking questions in three areas: questions with respect to the measurement of situation awareness (SA), questions with respect to our ability to train SA skills, and, finally, questions with respect to our ability to select people, early in the flying training process, who are likely to develop good SA at some point down the line.

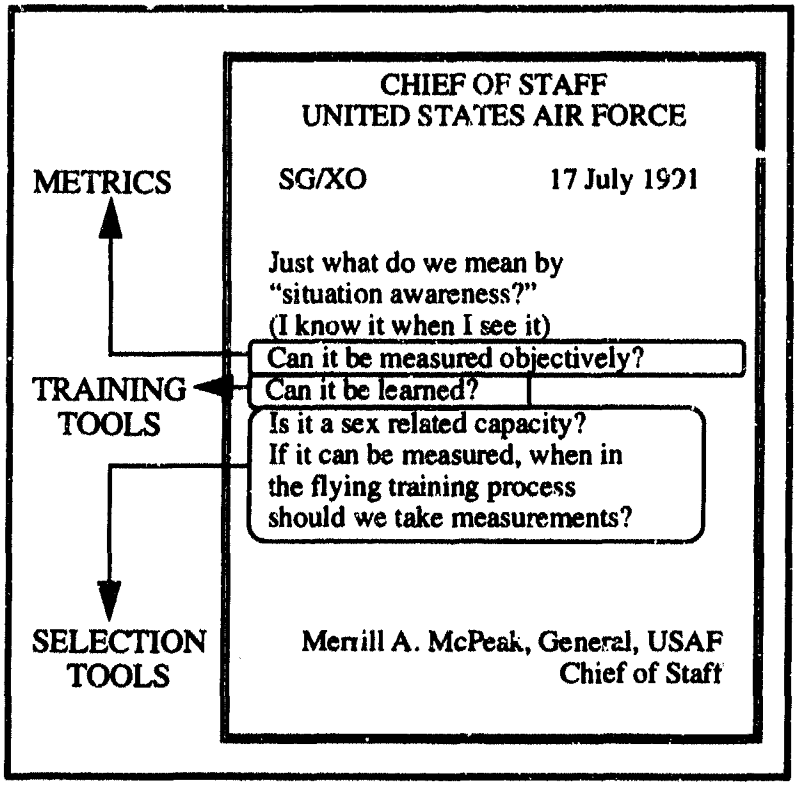


Figure 1. General McPeak's memo asking questions about pilot situation awareness.

In this presentation, I will closely follow the questions that he asked in the memo. First, I will give you an overview of the program. Then, I will review the findings of the study in the

three areas specified in the memo: measurement, training, and selection. Finally, I will give you a summary and an overview of our future plans.

Overview

The conduct of this study was truly an international effort involving a number of different organizations and operational units. The primary design and conduct of the study were in the United States, but we also collected data as far away as Kadena Air Force Base in Japan.

One of the first things our team did, when we were tasked with answering General McPeak's questions, was to identify a working definition. We adopted the definition of SA developed by an Air Staff SA working group:

> *A pilot's continuous perception of self and aircraft in relation to the dynamic environment of flight, threats, and mission, and the ability to forecast, then execute tasks based on that perception.*

A number of the elements of this definition are common to most definitions of SA, but there are some things that are different. The common elements include: perception of the state of the aircraft, the state of the environment, and the person's ability to forecast or predict into the future. But something that is unusual, and characteristic of the view of operational forces, is that SA includes the ability to execute tasks in combat.

Obviously, SA is a very complex construct. It is difficult to evaluate something going on inside a pilot's head. Since we cannot measure it directly, we have to make secondary measurements and draw inferences about SA. Essentially, there are two general techniques that can be used and, as you will see, we capitalized on both of them. First, one can measure or observe various aspects of a pilot's behavior (physical, verbal, etc.) in combat, in simulation, or during training exercises and make some inferences about their situation awareness. Alternatively, one can measure fundamental skills, abilities, and characteristics that are believed to be important for the development and maintenance of SA.

Figure 2 illustrates the overall structure of the study - the three main elements we used to answer the questions asked by General McPeak. First of all, we developed a variety of rating scales as a way to measure operational SA out in the field. The scale development effort was performed by Dr. Wayne Waag and his colleagues at the Human Resources Directorate in Mesa AZ. These were developed in several forms: rating scales that could be used by supervisors at an operational unit, rating scales that could be used by peers to rate one another in their wings and squadrons, a self-report scale that pilots could use to evaluate their own SA, and an observer form designed to evaluate SA in simulated air combat. The observer form was the primary instrument that we used in our simulator-based testing that's shown on the right side of Figure 2.

Essentially, these SA rating scales were designed to make the "I know it when I see it" process (a phrase often used to describe SA) systematic, repeatable, and reliable. I believe that we were successful, as you will see from the data presented later. We worked very closely with

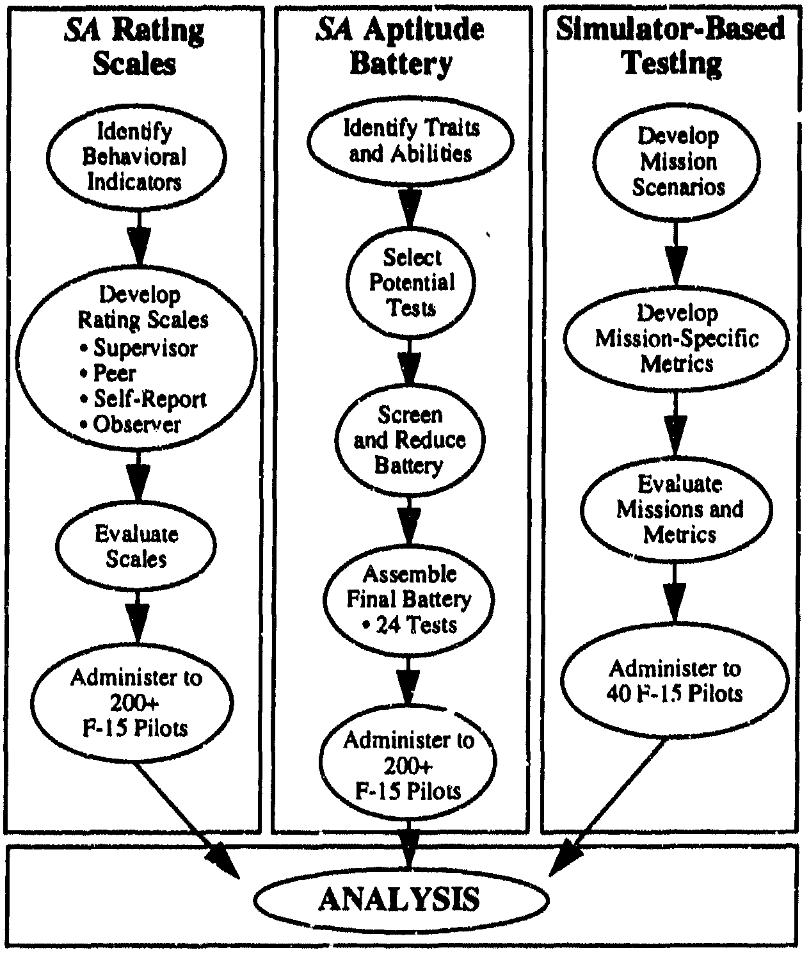


Figure 2. An overview of the research program.

pilots from a variety of units, including Luke Air Force Base, to identify the behaviors they were observing when they say, "This pilot has SA and this one doesn't." Basically, the rating scales sampled behaviors such as management of flight communication, selection of targets, selection of weapons, system management, and information interpretation and integration. We extensively evaluated the scales at Tyndall Air Force Base to make sure that pilots could use them easily and that they understood what we were asking them to rate. We then administered the scales to over 200 pilots in F-15 units at Eglin, Langley, Elmendorff, and Kadena Air Force Bases. The pilots in each of those units had ratings from 30-plus people, including the peer and supervisor evaluations.

The second element of our program is the SA Aptitude Battery. The effort to develop, implement, test, and run the aptitude battery portion of the program was performed by Major David Perry and his colleagues at the Human Resources Directorate, Brooks Air Force Base, TX. The SA Aptitude Battery is a set of computer based tests designed to measure traits, skills, and abilities that are important for the development and maintenance of SA. A total of 24 tests were selected based on our review of previous situation awareness research. The tests measured elements such as time management/temporal processing, the ability to perform multiple tasks at once, working memory capacity, spatial processing, the ability to recognize briefly-presented

targets, psychomotor skills, and personality variables. Most of the tests were already developed, but a few had to be refined for our application. There was extensive pre-testing with basic trainees and pilots before we reduced the final set down to 24 tests. The battery was then administered to the same pilots on whom we had the SA Rating Scale data.

The third element of the program focused on SA measurement in a demanding and controlled simulator environment. We used the Armstrong Laboratory simulator facility, located principally in Mesa, AZ. Forty pilots were selected from the initial set of over 200 to serve as experimental pilots. The pilots were selected to represent a broad range of SA performance, as indicated by their squadron ratings. In addition to the experimental pilots who were brought in two at a time from their units, we had live wingmen, ground control intercept (GCI) operators, AWACS operators (via a link to Dr. Schiflett's AWACS simulation at Brooks Air Force Base), two live threats, and up to four automated threats. The highly-scripted scenarios ranged from 1v2 up to 2v6. The experimental pilots were tested one at a time and flew 36 engagements over 5 days. We varied scenario difficulty by manipulating the amount of SAM activity, communications jamming, GCI and AWACS support, and the number and type of threats.

In the simulator, a variety of dependent variables were collected, including objective measures related to kills, time to acquire targets, and eye movement data. However, the primary measure that I'll be reporting today are the SA ratings given by two observers using the observer form of our SA Rating Scale. The two observers were highly trained, ex-Air Force pilots who were blind to the experimental pilots' squadron ratings.

SA COMPONENTS IDENTIFIED FROM PILOT DEFINITIONS	MOST HIGHLY RATED CAPABILITIES IN RATING SCALES
Building 3-D Composite Picture	Spatial Ability to Mentally Picture Engagement
Information Integration	Integrating Overall Information from Multiple Sources
Knowing Spatial Position and Geometry	Maintaining Track of Bogies and Friendlies
Updating Dynamic Situation	Use of Communication
Prioritizing Information and Actions	Time-Sharing Abilities
Quality and Timely Decisions	Adjusting Plan on-the-Fly
Projecting Situation into Future	Lookout for Threats from Visual, RWR, VSD

Figure 3. The key components of SA extracted from pilots' definitions of SA (left), and the elements that they rated as most important in the rating scales (right).

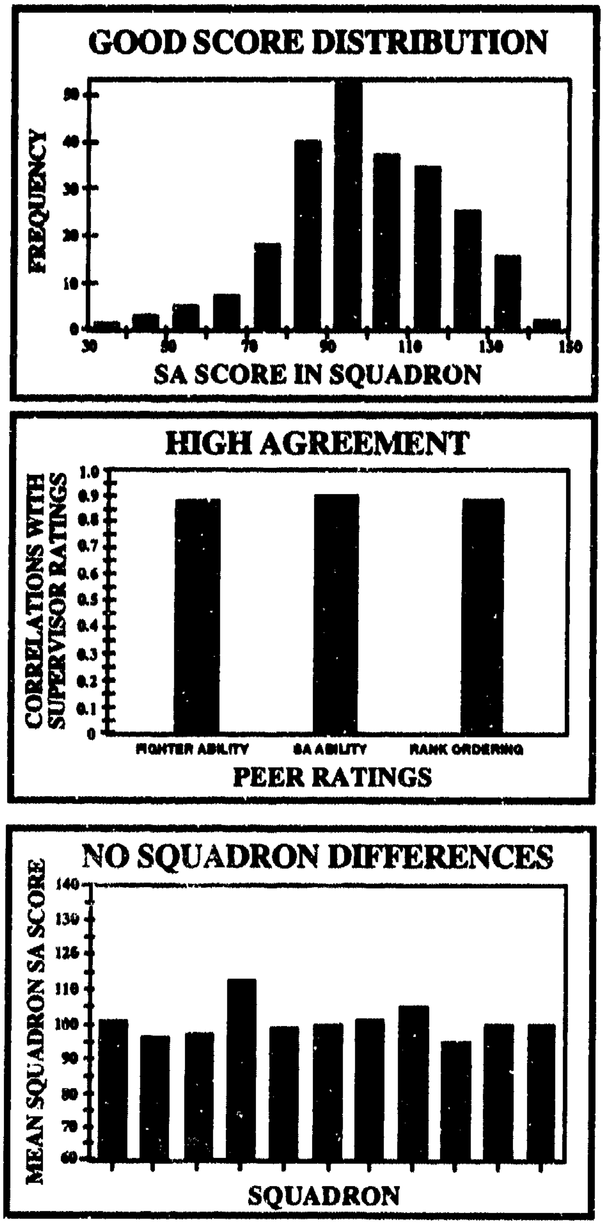


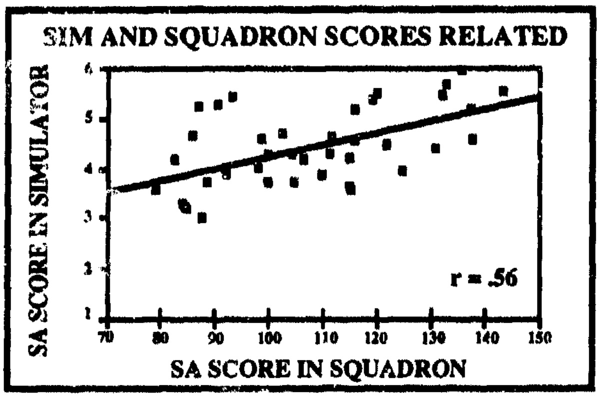
Figure 4. SA rating scale results from the in-squadron assessments of over 200 pilots.

Measurement

Turning now to the study findings, I will first address the issue of measurement. One of the first things that we did in testing was to ask the pilots for a personal definition of SA. What do they think it is? What are the key elements? As a first step in using the rating scales, they had to rate the importance of each of the rating scale elements. Figure 3 compares key SA components extracted from the pilots' definitions with the elements that they rated as most important in our rating scales. I think you will see a consistent picture there - the elements of building a 3-D composite picture of the battle, information integration, and so on down the list.

Clearly, there was agreement between what the pilots were stating in their definitions of SA and the elements included in our rating scales.

We believe that we can answer a strong 'yes' to the Chief's question about whether or not SA can be measured. We combined the peer and supervisor SA ratings and did a principal components analysis on them. Using the first principal component (which accounted for 92% of the variance), we observed a good distribution of squadron SA scores (Figure 4.). Obviously there is a spread of ability here. One of the things that pleasantly surprised us, shown in the figure labeled "High Agreement," was the consistency between the supervisor and peer ratings of the



IDENTIFIED INDICATORS OF POOR *SA*

- Reduced Communication
- Reduced Maneuvering
- Defensive Reaction
- Channelized Attention
- Poor Pre-Merge Kill Ratio
- Lost Awareness of Objectives

IDENTIFIED CRITICAL *SA* ABILITIES

- Leadership and Resource Management
- Decision Making
- Communication
- Tactics Knowledge
- Weapons Knowledge

Figure 5. Relationships between the in-squadron SA rating scale assessments and expert observer ratings of SA during simulated air combat.

same pilots. As you can see, those correlations are quite high - all in the .9 region. They definitely agreed on who the top and bottom pilots were. The correlations between the self-reported SA and the peer/supervisor ratings (not shown) were much lower, in the .4 to .5 range.

Another thing you will notice in the figure is that pilots don't make a strong distinction between fighter ability and SA ability. As far as they're concerned, those two things are tightly linked and if a pilot's got one, they've got the other. The third thing we found was that there was no significant difference in the average SA scores of the squadrons in which we made these measurements; one F-15 squadron wasn't significantly higher in terms of SA scores than the others. This is illustrated in the bottom part of Figure 4, and is another indication that the raters were using these scales in a similar fashion.

We also were successful in measuring SA in the simulator environment. Figure 5 shows some of these findings. We observed a good correlation between the squadron and simulation SA scores. While we did not expect a perfect relationship, the correlation (r = .56) implies that we are measuring some common ele... .. here. We also found that highly trained observers are a very effective way to make this type of measurement. When measuring a complex construct like SA, they can look past simulator deficiencies, they can identify "game-playing," and they can evaluate performance in the simu tor environment in a way that "objective" measures often can't. One of the things that they picked up consistently was indicators of poor SA: reduced communication, red..ced maneuvering, and so on. They also reported key characteristics of pilots who showed high SA

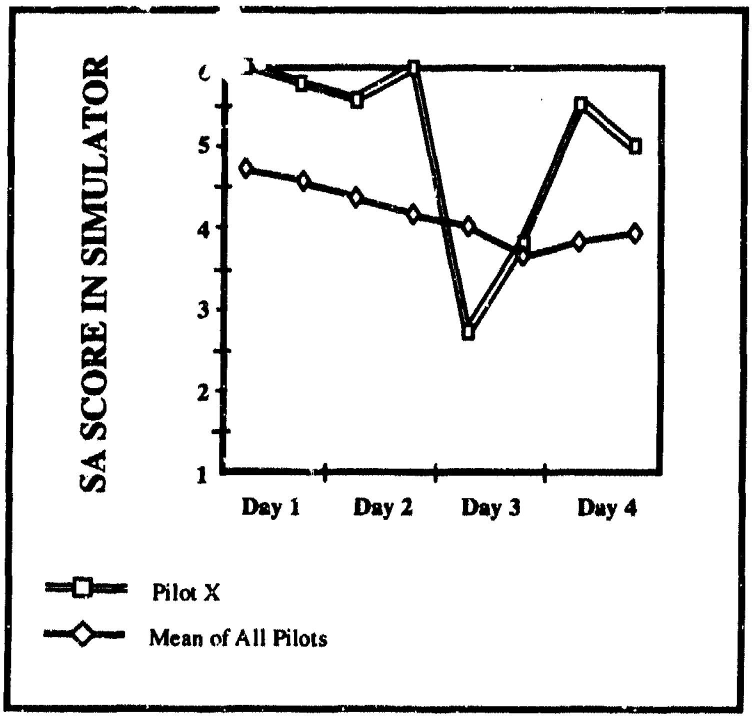


Figure 6. One pilot's dramatic shift in SA that was apparently caused by a family crisis.

Figure 6 presents some anecdotal data that has generated a great deal of interest. One curve in Figure 6 shows the average SA score for the 40 pilots who participated in the simulation phase of this study. It has a slight downward trend since the scenarios became more difficult as the week progressed. The other line shows the data from one pilot. He was a top performer; a fighter weapons school graduate who had high ratings in his squadron. On the initial scenarios, he performed beautifully. Then, on Day 3 (Wednesday), a marked drop occurred and he performed more poorly than the average of the other pilots. On Day 4, his performance came back up to well above average. When he was being debriefed, he told us that he received a call Wednesday morning that his 18-month old son was going into the hospital for emergency surgery. On Wednesday evening, he got a call that everything was fine. People often ask the question, "Are family crises going to affect SA out in the field?" These results suggest that this could be the case. We were equally interested in the fact that our observers picked it up. They were not overwhelmed by the halo effect of his performance on the first two days. They observed this marked drop in SA, even though they had no idea why it happened.

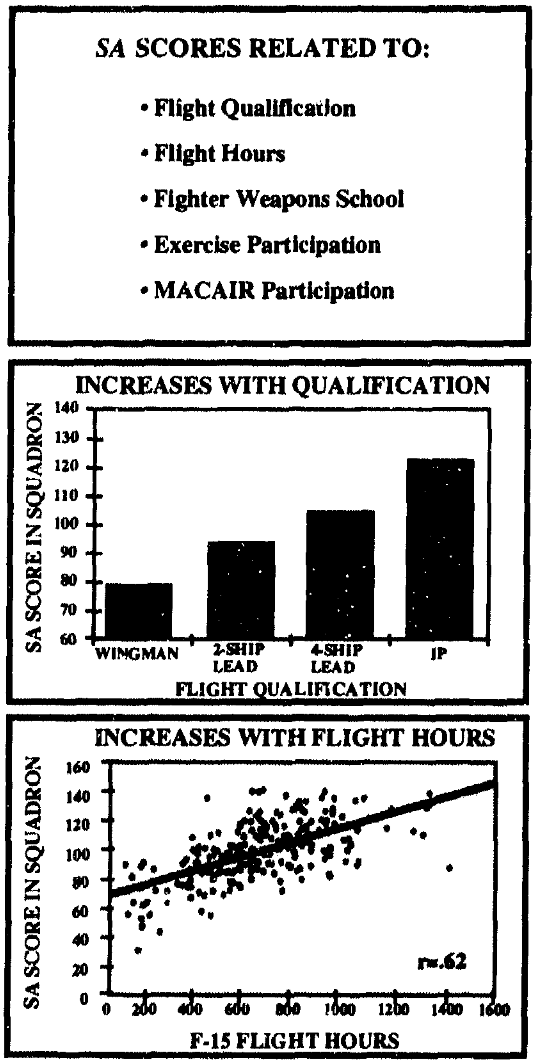


Figure 7. Impact of various training experiences on SA capabilities.

Training

Before discussing the training implications of this study, I must point out that these implications are based on correlational analyses. Because of time constraints, we could not run a rigorous learning or transfer-of-training study. In Figure 7, we show the relationship between certain training variables, training experiences, and the SA scores that were measured out in the squadron. We found that the squadron SA scores were statistically related to the flight qualification level, the number of flying hours, whether or not they'd been to fighter weapons school, participation in exercises such as Red Flag, Green Flag, Maple Flag, and even whether or not they had participated in other simulation exercises. The middle and bottom figures show the specific relationships between SA scores and flight qualification, and SA scores and flight hours. While no cause-and-effect relationships can be determined from these findings, the consistent pattern is noteworthy. Training experiences designed to enhance pilots' SA are associated with increased SA.

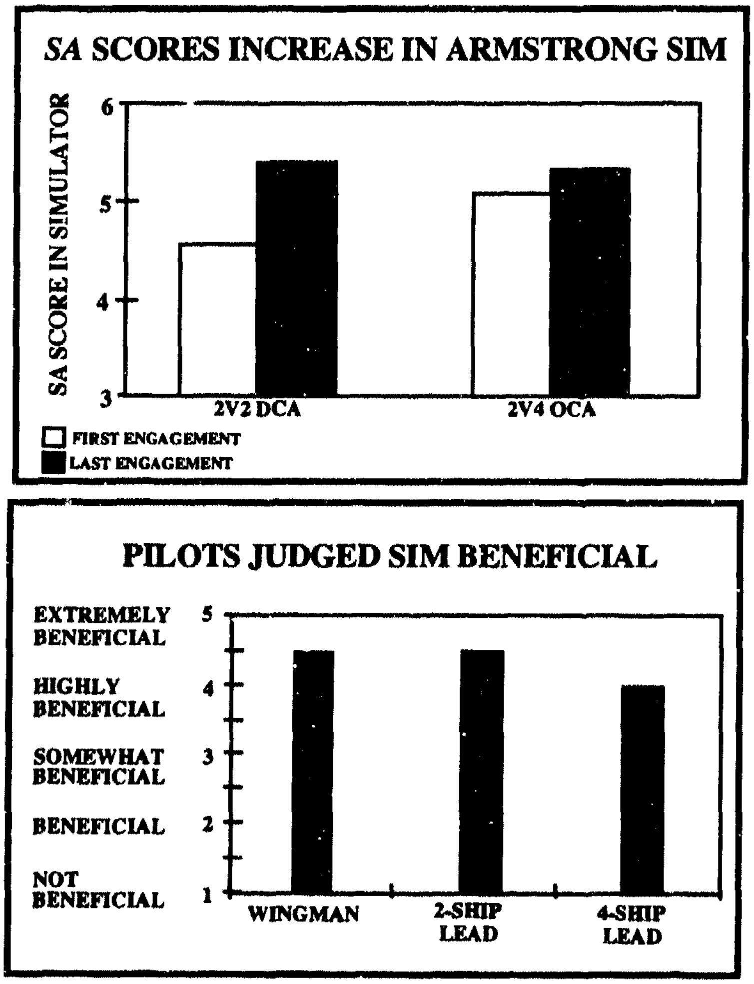


Figure 8. Impact of pilot practice on expert observer ratings of SA (top) and pilot assessments of benefit of this type of training experience (bottom).

More direct evidence of SA learning can be extracted from the simulator data. For example, in the Armstrong Laboratory simulator the pilots went through a total of 36 different engagements. The upper part of Figure 8 shows the SA score that they got on their first 2v2 defensive counter air sortie versus their last one, and their first 2v4 offensive counter air and their last one. In both cases, the SA scores improved. We also asked the pilots to evaluate the training benefit of interactive multi-ship simulation. The pilots overwhelmingly rated the Armstrong Laboratory simulation experience as highly or extremely beneficial for the development of SA skills. We had them rate the benefit for a wingman, a 2-ship lead or a 4-ship lead, and they felt that the simulator would be highly or extremely beneficial for all those qualification levels.

Selection

Our findings with respect to selection do not permit as clear an answer as we were able to offer in the measurement and training areas. We found that three abilities were related to (predicted) SA scores in the squadron: working memory capacity, multi-tasking ability, and spatial processing. We also found that the current Air Force selection system includes tests of these abilities as part of the Pilot Candidate Selection Model (PCSM). PCSM scores are one factor in selecting pilots for Undergraduate Pilot Training (UPT). Because PCSM has only recently been fielded, we don't know if PCSM scores will predict SA in mission-ready fighter pilots. We do know, however, that PCSM scores predict performance and attrition in UPT (Figure 9). It will take about 5-8 years until we have PCSM data on enough mission-ready pilots to determine if it is a useful SA selection tool. Nevertheless, our findings suggest that the current selection system is measuring the right abilities.

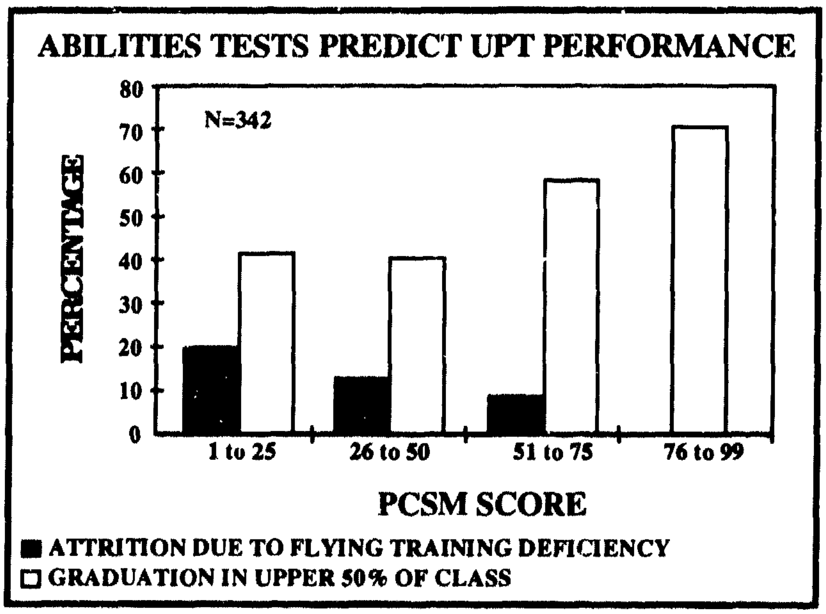


Figure 9. The relationship between Pilot Candidate Selection Model (PCSM) scores and pilot trainee success in Undergraduate Pilot Training (UPT).

General McPeak also asked the question, "Is there any evidence that SA skills are gender related?" Since we were only evaluating F-15 pilots, we could not address this issue directly. As an indirect measure, we looked in the literature for evidence of male/female differences on the three ability tests that were correlated with the SA scores: working memory capacity, multi-tasking ability, and spatial processing. We found no reported male/female differences on the particular tests or attributes that were significant predictors of SA in our study.

Conclusions

In summary, our findings suggest that SA can be measured using rating scales in an operational environment and using trained observers in a controlled-exercise environment . Our data suggests that the flying training process does enhance SA, and that it grows with a wide variety of operational experiences. Can we select for SA? A solid answer will require longitudinal tracking of pilots in the current selection and training pipeline, but we can use the data that we have collected to further refine the current process.

In the future, we plan to broaden our work in several areas. We will evaluate multi-ship simulation and cognitive skills training using controlled transfer-of-training designs. We will expand our SA research to other areas – other aircraft, other jobs, team SA, and so forth. We plan to track pilots through the operational process to see if tools such as PCSM can improve selection. Finally, we should remember that improved cockpit design has the potential to increase SA as much as training and selection. Thus, we plan to develop a set of measurement tools to assess the SA benefits of alternative cockpit designs.

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SECTION II -

ANNOTATED BIBLIOGRAPHY

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1. Adam, E.C. (1993). Fighter cockpits of the future. In *Proceedings of the AIAA/IEEE 12th Digital Avionics Systems Conference* (pp. 318-323). New York: Institute of Electrical and Electronics Engineers.

This paper presents Adam's views of the relationship between situation awareness and fighter cockpit design. Adam reviews the history of cockpit development, identifies potential limitations of current cockpit designs, and outlines potential future designs to improve the fighter cockpit. Historically, Adam suggests that we have been through two generations of cockpit designs: The first generation was characterized by (p. 318), "round dials to help the pilot keep the airplane flying right side up." The second generation of cockpit designs introduced multifunction displays and head-up displays (HUDs). Current fighter aircraft are examples of second-generation cockpits. Adam suggests that the current designs severely constrain fighter pilot performance for two reasons: (1) too much time is required to "fiddle" with aircraft systems rather than executing tactics, and (2) only 20% to 30% of the display area in the cockpit can be used for presenting useful combat information. Previously, the limited amount of reliable tactical information that was available within the cockpit could be presented and used with the above constraints. However, Adam believes that modern technologies, such as improving on-board sensors and data links, will profoundly increase the amount of data that must be presented to the pilot. It is suggested that this will cause major problems for the pilot as it is presented in little pieces that must be cognitively "fused" by the pilot. Adam then interprets potential improvements to cockpit designs within a SA framework. The definition issue is addressed briefly (p. 319): "So, what is SA, what is it all about? It's simply KNOWING WHAT'S GOING ON SO YOU CAN FIGURE OUT WHAT TO DO!" Adam subdivides overall SA into two main components: Global SA (the Big Picture), and Tactical SA (The Little Picture). In the near term, the tactical SA solution is seen to be helmet-mounted displays (HMDs). Global SA can be addressed by increasing the cockpit display area and fusing the data into a comprehensive picture on a Big Picture display. Several possible developmental steps towards developing such future cockpits are described.

KEYWORDS: air-to-air mission, air-to-ground mission, aviation (military), big picture displays, data fusion, data link, definition, display design, helmet-mounted displays (HMDs), pilot aiding

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2. Adam, E.C. (1994). Tactical cockpits - The coming revolution. In R.D. Gilson, D.J. Garland, and J.M. Koonce (Eds.), *Situational awareness in complex systems: Proceedings of a CAHFA Conference* (pp. 101-110). Daytona Beach, FL: Embry-Riddle Aeronautical University Press.

This article essentially presents the same definition and interpretations discussed in the Adam (1993) paper.

KEYWORDS: air-to-air mission, air-to-ground mission, aviation (military), big picture displays, data fusion, data link, definition, display design, helmet-mounted displays (HMDs), pilot aiding

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3. Adams, M.J., and Pew, R.W. (1990). Situational awareness in the commercial aircraft cockpit: A cognitive perspective. In *Proceedings of the IEEE/AIAA/NASA 9th Digital Avionics Systems Conference* (pp. 519-524). New York: Institute of Electrical and Electronics Engineers.

This paper is primarily concerned with generating a theoretical background for understanding SA within the commercial aircraft cockpit. Situation awareness (SA) is defined (p. 519) as the crew's "moment by moment ability to monitor and understand the state of the aircraft, its systems, and its environment." SA is seen as being intimately involved with mental workload. In fact, the authors contend (p. 520): "From our perspective, achieving situational awareness is but a special class of mental workload." In the discussion of the cognitive processes involved in maintaining SA, the authors emphasize the properties of the human memory system that allow it to contend with demanding real-time, cognitively complex tasks. Mental models, the organization of long-term memory, the nature of expertise, the integration of new information into an on-going process, and attentional limitations are among the issues that are discussed.

KEYWORDS: attention, aviation (civilian), cognitive processes, definition, expertise, mental models, workload

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4. Adams, M.J., Tenney, Y.J., and Pew, R.W. (1991, December). *Strategic workload and the cognitive management of advanced multi-task systems* (CSERIAC State of the Art Report 91-6). Wright-Patterson Air Force Base, OH: Crew System Ergonomics Information Analysis Center.

The main thrust of this report concerns a reappraisal of mental workload. The authors argue that the dominant view of workload as the demand and allocation of mental resources is too passive. This passivity is seen as especially inadequate when attempting to explain human performance in a dynamic multi-task environment with advanced automation aids. As an alternative, they present a theoretical framework that combines active theories of perception (primarily inspired by Neisser), connectionist theories from the Parallel Distributed Processing (PDP) school, and schema theories of text comprehension. This framework includes discussion of the interplay of information in the explicit focus of short-term memory along with associated information that is relevant to the ongoing processing, but outside awareness in an implicit focus. The issues of awareness in general, and situation awareness in specific, recur frequently throughout the manuscript. Many of the concepts discussed in this report are similar to those reviewed by Tenney et al. (1992) in their discussion of situation awareness in commercial aviation.

KEYWORDS: cognitive processes, expertise, review paper, schema, workload

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5. Alkov, R.A. (1994, April). Enhancing safety with aircrew coordination training. *Ergonomics in Design*, pp. 13-18.

This article is primarily a review of the rationale for applying an aircrew coordination training program to U.S. Navy and Marine Corps helicopter and fighter squadrons. The author reviews accident statistics that demonstrate that human error is a major contributor to U.S. Navy and Marine Corps helicopter and fighter mishaps. The author contends that poor pilot coordination, faulty pilot judgment, and loss of situational awareness are important contributors to many of these mishaps. Among the causes of loss of situation awareness the author lists distraction, ambiguous information, work overload, and poor communication. In particular, the author emphasizes the potentially damaging effects of too much workload on SA (p. 16): "If a pilot has to use large amounts of working memory to fly the aircraft, those resources can't be used to scan the environment for information needed to maintain situational awareness." As a means to alleviate some of the problems that can cause aircraft mishaps, a program to train aircrew coordination is advocated. In tests of the program, participants have reported that they feel it was beneficial and accident statistics following the program showed a marked decrease in the mishap rates due to aircrew error.

KEYWORDS: aviation (military), cockpit resource management (CRM), helicopter, pilot error, team decision making, team SA, training, workload

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6. Anderton, D.A., Soras, C., and Lewis, W.R. (1988, April 11). Market Supplement: Cockpit Technology. *Aviation Week & Space Technology, 128*(15), 57-98.

This market supplement contains an introduction and 5 articles. SA is prominent in the introduction and in the first two articles. In the introduction, improving SA is identified as a major goal for new cockpit technology development in both military and commercial aviation. The first article, *Revolution in the Cockpit*, emphasizes the emergence of revolutionary new technology in the military cockpit and the effects on SA. Among the topics discussed are "big picture" displays, helmet-mounted displays, and advanced automation in avionics. The second article, *Automating the Two Crew Flight Deck*, discusses the development of the "glass cockpit" for commercial aviation. These systems are promoted as a means to increase SA while reducing workload.

KEYWORDS: aviation (civilian), aviation (military), avionics, big picture displays, display design, helmet- mounted displays (HMDs), pilot aiding

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7. Andre, A.D., Wickens, C.D., Moorman, L., and Boschelli, M.M. (1991). Display formatting techniques for improving situation awareness in the aircraft cockpit. *The International Journal of Aviation Psychology, 1*, 205-218.

The influence of display perspective, frame of reference, and color on situation awareness in aircraft navigation was assessed. The authors expressed doubts about the appropriateness of subjective recall procedures for situation awareness assessment. Regardless of whether the situation awareness probes were presented during the actual performance of the task or in a retrospective setting, the issue of developing an appropriate method for eliciting subjective recall of the relevant aspects of the situation was considered daunting. As the authors put it (p. 209): "Given the inherent ambiguity of situation awareness as an operational construct, there can be any number of possible 'details' relevant to the mission. Hence, the validity of each recall procedure is dependent more on the structure of the subjects' report than on the efficacy of the display formats in question." As an alternative to memory-probe-based situation awareness metrics, the authors developed performance tests based on how adaptively the subjects achieved appropriate orientation to the next waypoint in the simulated task after a disruption and how often they controlled multiple axes of the aircraft. The results indicated that 3-D perspective as presented in this experiment did not improve overall navigation performance, but did support better multi-axis control strategies. Also, the nontraditional, outside-in reference frame was superior to the traditional, inside-out display. Overall, the experiment provides an example of using the situation awareness concept to help guide a display evaluation. Although the specific measures used in the research will probably not generalize to other evaluations, the general approach might be useful in other settings.

KEYWORDS: display design, measurement, memory probe measures, performance-based measures

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8. Arbak, C.J., Schwartz, N., and Kuperman, G. (1987). Evaluating the panoramic cockpit controls and displays system. In *Proceedings of the Fourth International Symposium on Aviation Psychology* (pp. 30-36). Columbus: The Ohio State University.

The authors argue that the iterative addition of new systems to the cockpit over the years has created a situation awareness problem for the pilot. Such systems sometime display the same information in different formats and require the pilot to perform the difficult job of information fusion. The Panoramic Cockpit Controls and Displays System (PCCADS) was developed as a means to help future pilots. PCCADS combined a large "big picture" display system with innovative controls technology. The goal was to increase performance and situation awareness while reducing workload. The authors discussed some of the complex ways that performance, situation awareness and workload might interact. For a planned evaluation of PCCADS the authors had developed a subjective situation awareness scale. The scale was based on a Tactical Air Command definition of situation awareness and consisted of six questions about situation awareness, each of which was answered by selecting a response from a seven point scale. The authors reported that the scale appeared to be sensitive to a manipulation of situation awareness in a preliminary study.

KEYWORDS: aviation (military), big picture displays, display design, measurement, pilot aiding, subjective measures, workload

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9. Aretz, A.J. (1988). A model of electronic map interpretation. In *Proceedings of the Human Factors Society 32nd Annual Meeting* (Volume 1, pp. 130-134). Santa Monica, CA: Human Factors Society.

The author argues that one component of situation awareness is navigation awareness (Am I where I think I am?). Electronic map displays are being developed for the cockpit that are intended to improve navigational awareness. The author proposed and tested a model of the cognitive processes that would be needed to interpret an electronic map display. Complexity of the display was found to have a significant effect; but, somewhat surprisingly, the effect of rotation of the display was found to be minor.

KEYWORDS: aviation (civilian), cognitive processes, definition, display design, measurement, performance-based measures

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10. Aretz, A.J. (1991). The design of electronic map displays. *Human Factors, 33,* 85-101.

The paper does not discuss the overall concept of SA, but discusses navigational awareness which can be considered to be one aspect of SA. The author presents a theoretical framework in which navigational awareness is viewed as (p. 85), "the maintenance of a cognitive coupling between two reference frames (RFs) that correspond to the map and the forward view of the world." The paper discusses the cognitive issues involved in using maps to aid navigational awareness, possible alternative map display formats, and the concept of "visual momentum" as a display guideline applicable to map display design. The results of an experiment are interpreted as supporting the notions that navigational awareness involves cognitively aligning two frames of reference, that this cognitive activity competes with other cognitive activities for limited resources, and that the visual momentum concept is a useful display design tool.

KEYWORDS: attention, cognitive processes, design guidelines, display design, measurement, multiple resource theory, performance-based measures, pilot aiding, subjective measures, workload

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11. **Ballard, D., and Owsley, L. (1991). Artificial intelligence in the helicopter cockpit of the future. In *Proceedings of the IEEE/AIAA 10th Digital Avionics Systems Conference* (pp. 125-130). New York: Institute of Electrical and Electronics Engineers.**

This article discusses the architecture and design issues for an artificially intelligent Situation Assessment device to be used in military helicopters. The Situation Assessment device is based on technology developed by the DARPA (Defense Advanced Research Projects Agency) and the US Air Force for the Pilot's Associate (PA) program and is intended to support the US Army's Rotorcraft Pilot's Associate (RPA) Advanced Technology Transition Demonstration (ATTD) Program. The Situation Assessment device is on part of a planned cognitive decision aiding technology that will assist the pilot in formulating his/her situation awareness by (p. 126), "recognizing hostile and unknown threats and prioritizing them with respect to threat lethality." The authors adopt the following definition of situational awareness (P. 126): "Situational awareness is knowing:
- Where friendly ground and airborne forces are and what they are doing;
- Where threats are and what they are doing;
- What ownflight knows and options for offense/defense;
- What other flights know and their intentions, and finally and perhaps most importantly,
- What part of the above is not known or is missing."

KEYWORDS: aviation (military), avionics, decision aiding, definition, helicopter, pilot aiding

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12. Ballas, J.A., Heitmeyer, C.L., and Perez, M.A. (1991). Interface styles for adaptive automation. In *Proceedings of the Sixth International Symposium on Aviation Psychology* (Volume 1, pp. 108-113). Columbus: The Ohio State University.

This research investigated the use of graphical direct manipulation displays to reduce the possibility that automation would degrade SA. The subjects performed a laboratory dual task combining a tracking task and a target classification task. The difficulty of the tracking varied over time. As the tracking became difficult, the target classification task would adaptively shift to an automated state in which the subjects merely confirmed the classification. The display for the target automation task was either graphical (with icons) or tabular, and responses to the target identification task were either through a keypad or via a touch screen. The hypothesis was that a direct manipulation interface (e.g., the combination of graphical presentation and touch screen response) would allow better and more efficient maintenance of SA than would a non-direct manipulation display (e.g., tabular display with keypad response). Although the data collection had not been completed there was a non-significant trend in the performance data that suggested that joint performance of the two tasks benefited from the graphical presentation. The issue of SA was also addressed in a debriefing questionnaire. Subjects that used graphical displays rated their ability to anticipate changes in automation level significantly higher than subjects that used the tabular displays.

KEYWORDS: aviation (military), avionics, measurement, performance-based measures, pilot aiding, questionnaire/survey data, retrospective measures, subjective measures, target identification

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13. Barbato, G.J., and McCracken, J.R. (1993). Crew system design alternatives for single seat fighters. In *Proceedings of the Seventh International Symposium on Aviation Psychology* (Volume 1, pp. 98-102). Columbus: The Ohio State University.

This project is part of an on-going program to investigate the most effective approach for incorporating data-linked information into a tactical fighter cockpit. The source of the data-linked data might be air-based or ground-based radar systems, or the sensors from other fighters. Several display options were tested by six active or former military fighter pilots. Both objective (i.e., deviation from flight path, number of switch closures, etc.) and subjective (questionnaire) data were collected. The data suggested that the pilots preferred the combination of a Sensor Volume Display (that showed the portion of space being scanned by the pilot's aircraft and his wingman's aircraft) and a Tactical Situation Format display (that showed a symbolic representation of the battle area and actors from a bird's-eye view). The subjective data also suggest that the pilots favor the development of display devices with much larger display areas than are currently available (i.e., big picture displays).

KEYWORDS: aviation (military), avionics, big picture displays, combat simulation, data fusion, data link, display design, measurement, performance-based measures, pilot aiding, questionnaire/survey data, subjective measures

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14. Beach, M. (1990). Cooperative tactical operations using a data link. In *Proceedings of the IEEE/AIAA/NASA 9th Digital Avionics Systems Conference* (pp. 549-551). New York: Institute of Electrical and Electronics Engineers.

The author discusses the design requirements and benefits for a data link system connecting combat aircraft. Overall, he interprets the functions of a data link system in three categories: situation awareness, offensive functions, and defensive functions. In introducing the SA benefits of data link, the author states (p. 549): "The most fundamental benefit of sharing information with a wingman is the increase in situation awareness. In order to get this situation awareness, track files must be exchanged as a minimum." Track files are the information from the aircraft's sensor systems (primarily radar) on the attributes (e.g., location, altitude, heading, speed, identity, etc.) of other aircraft. The author points out that for technological reasons this will be the most challenging information to exchange across the data link, but suggests that it is the most essential. The impact on SA is that the pilot of an aircraft will gain information about aircraft that his own sensors are not assigned to track or are unable to track.

KEYWORDS: air-to-air mission, aviation (military), avionics, data link, pilot aiding

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15. Beringer, D.B., and Hancock, P.A. (1989). Exploring situational awareness: A review and the effects of stress on rectilinear normalization. In *Proceedings of the Fifth International Symposium on Aviation Psychology* (Volume 2, pp. 646-651). Columbus: The Ohio State University.

The authors start the review with a discussion of the lack of a consensus definition of situation awareness. They then suggest that SA in human/machine systems be defined (p. 646), "as conscious awareness of actions within two mutually embedded four-dimensional envelopes." The two envelopes are: the "inner" envelope (unaided sensory space), and the "outer" envelope (information available via remote sensing). A hierarchical model of the component processes required for situation awareness is described. The model has three levels: (1) A Higher Macro-level: maintaining orientation, maintaining action priorities, integrating subtasks, and monitoring cues; (2) A Lower Macro-level: the requisite skills and activities to feed the necessary information to the higher level (detection, differentiation, diagnosis, and inference); (3) A Micro-level: detection and differentiation of information as influenced by stimulus factors. The authors suggest that there are five potential methods for improving situation awareness in the cockpit: selection, training, system improvement, system design, and compensation for stress. As an example of a componential approach to situation awareness research, the authors describe a laboratory study that was designed to examine the relationship between stress (inflicted by varying time-sharing demands) and spatial memory of a course. Only preliminary results were presented, but based on these data the authors conclude (p. 650) "It is clear that training or experience is useful in facilitating performance of this type of task, suggesting that enhancement of component skills through training may be one route to the overall enhancement of SA."

KEYWORDS: cognitive processes, definition, measurement, retrospective measures, subjective measures, training

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16. Betts, F.C. (1987, January). *Situational Awareness Study (SAS), Volume 1, Executive summary* (Tech. Report No. AFWAL TR-86-1150-Vol-1). Wright-Patterson Air Force Base, OH: Air Force Wright Aeronautical Laboratories. (AD-B121972)

The main product of this study was software which facilitates data reduction and evaluation of man-in-the-loop simulations of fire control systems. The study evaluates data from an advanced medium-range air-to-air missile operational utility evaluation (AMRAAM OUE) and from a multi-sensor integration (MSI) system simulation. The SAS software helped illustrate system requirements which will lead to two specific improvements in pilot situational awareness of adversaries: (1) better weapons usage, and (2) higher survivability rates.

KEYWORDS: air-to-air mission, aviation (military), avionics, combat simulation, data fusion, measurement, performance-based measures

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17. Biferno, M.A., and Stanley, D.L. (1983). *The touch-sensitive control/display unit: A promising computer interface* (SAE Paper No. 831532). Warrendale, PA: Society of Automotive Engineers.

The authors present a description of a new interface device called a touch-sensitive control/display unit (touch-CDU). The touch-CDU allows the system operator or pilot to interact with a system by touching the display elements which could then be changed to present new information or to offer new options. Although neither the data collection nor analysis procedures are described within this paper, the authors state (p. 411): "Preliminary work has indicated that a great improvement in crew workload and increased situational awareness can be obtained by the thoughtful application of touch-CDUs to certain tasks."

KEYWORDS: aviation (civilian), display design, workload

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18. Blanchard, R.E. (Panel Chair) (1993). Situation Awareness: Transition from theory to practice. In *Proceedings of the Human Factors and Ergonomics Society 37th Annual Meeting* (Volume 1, pp. 39-42). Santa Monica, CA: Human Factors and Ergonomics Society.

This set of abstracts summarizes a panel session. A unifying theme to the session was that the theoretical framework for SA, while not complete, was sufficient to support research in applying the SA concept. Four abstracts follow the introduction: Mica Endsley (*Situation Awareness: The Development and Application of a Theoretical Framework*), Richard Mogford (*The Importance of Situation Awareness*), Mark Smolensky (*Toward the Physiological Measurement of Situation Awareness: The Case for Eye Movement Measurements*), and Mark Rodgers (*Use of Incident Re-creation for Studying Situation Awareness*).

KEYWORDS: attention, cognitive processes, decision making, expertise, measurement, memory probe measures, mental models, performance-based measures, physiological measures

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19. Bolstad, C.A. (1991). Individual pilot differences related to situation awareness. In *Proceedings of the Human Factors Society 35th Annual Meeting* (Volume 1, pp. 52-56). Santa Monica, CA: Human Factors Society.

The author cites previous research that had demonstrated that large individual differences existed in the generation and maintenance of SA. This implied that SA "may be trainable" (p. 52). The research in this paper involved giving 21 experienced military pilots a battery of cognitive tests to determine if any specific abilities correlated with SA measured in a simulator. Based on a literature review conducted by the author, the tests in the battery were selected to assess the subjects' abilities in six domains: spatial abilities, attention, memory, perceptual abilities, cognition, and personality. SA was assessed by an abbreviated version of SAGAT. Some significant correlations between performance on battery tests and SA in the simulation were discovered. The largest correlation was between the test of attention sharing ability and SA, followed by tests of immediate/delayed memory and encoding speed. The author proposes further work to explore these relationships and suggests (p. 55) that "Future evaluations will lead to the development of instructional methods for enhancing SA and could help identify the most promising areas for research and development in SA training."

KEYWORDS: attention, aviation (military), cognitive processes, combat simulation, individual differences, measurement, memory probe measures, performance-based measures, SAGAT, training

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20. Bond, D.F. (1992, May 11). Army evaluating Longbow, weighs broader program. *Aviation Week & Space Technology, 136*(19), 42-44.

The article describes proposed changes to the Army's AH-64A attack helicopters to upgrade them to AH-64C/D Apache Longbow helicopters. The proposed changes include extensive upgrading of the avionics with a new millimeter-wave radar, communications and navigational improvements, and an improved data modem (IDM). The IDM is considered to be a key interface for the Longbow system. The potential for this system was described by Charles Vehlow (McDonnell Douglas chief of AH-64 derivatives programs) as follows (p. 44), "The AH-64A's target acquisition and designation system limits situational awareness to consideration of individual targets in sequence." By contrast, the Longbow system will detect well over a dozen targets, classify them by type (armor, wheeled vehicles, air defense weapons and the like) and prioritize them according to how threatening they are. All this information will be shown to crewmembers on the tactical situation display." By using the IDM to exchange this information with other helicopters, the Longbow helicopter can act as a "battle captain" to ensure effective use of the available forces and avoid attacks on friendly forces.

KEYWORDS: avionics, data fusion, display design, fratricide, helicopter, pilot aiding, target identification

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21. Bowers, C.A., Braun, C., and Kline, P.B. (1994). Communication and team situational awareness. In R.D. Gilson, D.J. Garland, and J.M. Koonce (Eds.), *Situational awareness in complex systems: Proceedings of a CAHFA Conference* (pp. 305-311). Daytona Beach, FL: Embry-Riddle Aeronautical University Press.

This study investigated the relationship between communications patterns and performance of teams in simulated flight scenarios that were designed to demand high levels of SA. The subjects were IFR-rated pilots. The High-SA flight was simulated using Flight Simulator 4.0 on a desktop computer system. The High-SA flight was a low level reconnaissance flight that required subjects to identify buildings. The various teams were divided into high and low performance groups. The communications patterns of these groups were contrasted. No statistically significant differences were detected between the two groups in communications rate in any of the predefined categories. However, there was some evidence that the pattern of occurrence of statements from the different communications categories could discriminate between the low and high performance groups. The authors concluded (p. 310): "These results indicate that pattern analysis of communications is a promising tool for understanding the nature of SA in teams. However, it should be noted that these results are based on a very small sample size flying one relatively unique type of mission. Future research should assess the degree to which these results generalize across aircraft and mission requirements."

KEYWORDS: aviation (civilian), measurement, subjective measures, team SA, verbal protocols

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22. Braune, R. (1987). Summary of the workshop on cockpit automation in commercial airplanes. In *Proceedings of the Fourth International Symposium on Aviation Psychology* (pp. 9-15). Columbus: The Ohio State University.

This workshop convened to consider persisting problems in the application of automation to commercial airplane cockpits. The first issue listed for them to consider (on a list of 10 issues) was "Loss of situational awareness." In the summary of the discussions by the panel, the issue of SA was presented in the context of display technology and the pilot's understanding of what the automation is doing (p. 13): "Every effort should be made to use display technologies to help the pilot develop and maintain a maximum of situational awareness. A basic assumption is that the pilot should be able to fly the airplane manually or monitor automatic flight with an equal level of efficiency. Only if this can be accomplished can we be assured that the pilot's monitoring of the automatic systems is effective, i.e., the pilot fully understands what the automatic system is doing."

KEYWORDS: aviation (civilian), avionics, display design, pilot aiding

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23. Brookes, A. (1991). *Crash! Military aircraft disasters, accidents and incidents.* London: Ian Allan Ltd.

This book is not explicitly about SA, but SA is mentioned occasionally. The book reviews numerous military aircraft accidents, many of which involve lack of SA. Of particular interest is the chapter "Finger Trouble" which discusses an attempt by the RAF to increase "flight safety awareness" during World War II. The effort involved the creation of a fictional cartoon character, Pilot Officer Prune, who illustrated many unsafe activities in a humorous way. Among other responsibilities, Pilot Officer Prune was Patron of the Most Highly Derogatory Order of the Irremovable Finger, a monthly award commemorating outstanding examples of doing the "wrong thing at the wrong time while flying" (p. 45). This led to the use of the term "finger trouble" as an admonition to a pilot or crew member to get his act together. No data are presented to demonstrate that this effort increased flight safety in the RAF, but "finger trouble" seems like a precursor to the concept of SA.

KEYWORDS: aviation (military), pilot error

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24. Bunecke, J.L., Povenmire, H.K., Rockway, M.R., and Patton, M.W. (1990, April). The situational awareness component of cockpit resource management. In *Proceedings of the Psychology in the Department of Defense Twelfth Symposium* (Tech. Report No. USAFA-TR-90-1, pp. 259-263). Colorado Springs, CO: US Air Force Academy. (AD-A240113)

This article investigated the role of crew communication in maintaining SA in a simulated B-52 combat mission. During the simulated mission, all communications among the B-52 crew-members were recorded and then analyzed for their contribution to Cockpit Resource Management (CRM).
The frequency of the various classes of messages was correlated with the ratings of crew performance as assessed by expert observers and bombing accuracy. Overall, the amount of crew communication was found to correlate positively with the expert ratings of crew performance. The authors makes suggestion about how communication can be effectively used to increase crew SA and distribute crew workload.

KEYWORDS: air-to-ground mission, aviation (military), cockpit resource management (CRM), combat simulation, measurement, performance-based measures, subjective measures, team SA, verbal protocols, workload

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25. Busquets, A.M., Parrish, R.V., Williams, S.P., and Nold, D.E. (1994). Comparison of pilots' acceptance and spatial awareness when using EFIS vs. pictorial display formats for complex, curved landing approaches. In R.D. Gilson, D.J. Garland, and J.M. Koonce (Eds.), *Situational awareness in complex systems: Proceedings of a CAHFA Conference* (pp. 139-167). Daytona Beach, FL: Embry-Riddle Aeronautical University Press.

This paper reviews an investigation of the effects of using pictorial "pathway in the sky" displays rather than the current Electronic Flight Information Systems (EFIS) displays (with and without a Flight Director on the spatial awareness component of situation awareness. The experiment was conducted in a simulator using 16 commercial airline pilots as subjects. Situation awareness was measured by a variety of means: aircraft control performance, anomalous cues/detection time (a variation of an implicit technique), two versions of probe techniques (including a memory probe measure), and subjective questionnaires (including questions concerning workload). Overall, the results supported the value of the pictorial "pathway in the sky" displays. These displays appeared to increase spatial awareness while reducing the workload experienced.

KEYWORDS: aviation (civilian), display design, implicit measures, measurement, memory probe measures, performance-based measures, questionnaire/survey data, subjective measures, workload

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26. Calhoun, G.L., Janson, W.P., and Valencia, G. (1988). Effectiveness of three-dimensional auditory directional cues. In *Proceedings of the Human Factors Society 32nd Annual Meeting* (Volume 1, pp. 68-72). Santa Monica, CA: Human Factors Society.

This research investigated the potential benefits of 3-D audio in the cockpit. More specifically, the authors suggested that 3-D audio could provide three advantages: (1) increasing situational awareness of attitude, threats, and terrain, (2) enhanced communication intelligibility, and (3) cuing on where to look for peripheral cues. The experiment investigated the cuing properties of 3-D audio. The results supported the utility of 3-D audio. Localized auditory cues promoted improved acquisition of peripheral cues compared to either coded tones or speech messages. The authors concluded that (p. 72), "The results from the present study suggest that the use of 3-D audio aural signals as natural directional cues will allow the pilot to quickly and naturally construct a mental image of the situation with little expenditure of mental processing resources."

KEYWORDS: 3-D audio displays, attitude displays, display design, measurement, performance-based measures

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27. Canan, J.W. (1993, April). Space support for the shooting wars. *Air Force Magazine, 76*(4), 30-34.

General Charles A. Horner was the three-star air component commander of U.S. Central Command (CENTCOM) and of allied coalition air forces during the Gulf War. This article reviews his approach to his new job as the four-star General commander-in-chief of the multi-service U.S. Space Command. A major theme throughout General Horner's plans for Space Command is improving the direct communication between satellite intelligence assets and the soldier or pilot at the front of a battle. Among the systems mentioned are Global Positioning System (GPS) terminals for the cockpits of combat aircraft and the Talon Sword data link. The benefits of such systems are justified by the expected increase in aircrew situation awareness. General Horner expects that the increase in situation awareness that results from such systems will increase combat effectiveness and reduce the probability of fratricide.

KEYWORDS: aviation (military), avionics, data link, fratricide, pilot aiding

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28. Carmody, M.A., and Gluckman, J.P. (1993). Task specific effects of automation and automation failure on performance, workload, and situational awareness. In *Proceedings of the Seventh International Symposium on Aviation Psychology* (Volume 1, pp. 167-171). Columbus: The Ohio State University.

The research investigated the effect of the nature of an operator's mental model on recovery from a simulated automation failure. Tasks were divided into two categories: stable and dynamic. Stable tasks were those in which the information relevant for decision making, and especially diagnosis, did not change over time. Dynamic tasks were those in which the information required for decision making does change over time. It was hypothesized that the SA loss produced by an automated system would be more profound for dynamic tasks. Two laboratory studies using the Multiattribute Task (MAT) battery were conducted to test the hypothesis. In one of the studies, the Situation Awareness Global Assessment Technique (SAGAT) was used as a metric of situation awareness. Based on the results, the authors concluded that the stability of the internal cognitive model was an important distinction in interpreting the effects of automation.

KEYWORDS: cognitive processes, decision aiding, decision making, measurement, memory probe measures, mental models, performance-based measures, SAGAT

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29. Carr, L.A., and Lopina, R.F. (1982). Pilot workload in the night attack mission. In *Proceedings of the IEEE 1982 National Aerospace and Electronics Conference - NAECON 1982* (Volume 2, 881-884). New York: Institute of Electrical and Electronics Engineers.

The paper reviews the work conducted by the Night Attack Workload Steering Group (NAWSG). The NAWSG was concerned with the implementation of night-vision devices (such as the Low Altitude Navigation and Targeting for Night (LANTIRN) system) to fighter and attack aircraft. A major problem with implementing these systems was perceived to be the extremely high workload incurred by their use. The workload in such aircraft was seen to be closely related to pilot SA. For example, in discussing possible solutions the authors state (p. 883): "One of the key and potentially the most significant factors in reducing pilot workload is to enhance the pilot's situational awareness. Some of the more lucrative systems for consideration are moving map displays, integrated color displays, wide field of view heads up displays, and a very accurate inertial navigation system."

KEYWORDS: aviation (military) avionics, display design, workload

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30. Carretta, T.R., Perry, D.C., and Ree, M.J. (1994). The ubiquitous three in the prediction of situational awareness: Round up the usual suspects. In R.D. Gilson, D.J. Garland, and J.M. Koonce (Eds.), *Situational awareness in complex systems: Proceedings of a CAHFA Conference* (pp. 125-137). Daytona Beach, FL: Embry-Riddle Aeronautical University Press.

This paper reviews the design of an investigation of developing SA selection tools for use by the U.S. Air Force. Previous attempts to study the use of selection tests for SA abilities have suffered from limited sample size. This research will use a sample of about 200 F-15 pilots to provide a more reasonable level of statistical power. A large battery of selection tasks will be tested. The tasks will be based on a fundamental set of the "ubiquitous three" in selection research (i.e., psychometric g, psychomotor skill, and the personality construct of "conscientiousness") and supplemented by various tasks suggested in the SA literature. The task battery will combine both performance-based tests and subjective measures as potential correlates of SA abilities. The data from these tasks will be tested against a criterion SA-rating collected from the pilots, their commanders, and their peers. At the time of the writing, the data collection was not complete, so no data are presented. (NOTE - this project is part of the SAINT team research reviewed by McMillan in this Technical Report.)

KEYWORDS: aviation (military), cognitive processes, individual differences, measurement, performance-based measures, subjective measures

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31. Carroll, L.A. (1992, March). Desperately seeking SA. *TAC Attack (TAC SP 127-1), 32*(3), 5-6.

The author discusses the importance of situation awareness to Air Force operations. An Air Staff process action team was formed to answer the questions (p. 5): "Just what do we mean by situational awareness? Can it be measured objectively? Can SA be learned? Can we select for it? If it can be measured, when in the flying training process should we take measurements?" The Air Staff team proposed the following operationally- oriented definition for situation awareness (p. 6), "a pilot's (or aircrew's) continuous perception of self and aircraft in relation to the dynamic environment of flight, threats, and mission, and the ability to forecast, then execute tasks based on that perception." The author points out that current programs involving the training of spatial orientation, task and attention management, crew coordination, and so on, are related to the creation and maintenance of situation awareness. However, these are not considered to be sufficient and the author proposes that (p. 5), "SA should be the umbrella under which applicable human factors research and training are pursued."

KEYWORDS: attention, aviation (military), cognitive processes, definition, training

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32. Chandra, D., and Bussolari, S.R. (1991). An evaluation of flight path management automation in transport category aircraft. In *Proceedings of the Sixth International Symposium on Aviation Psychology* (Volume 1, pp. 139-144). Columbus: The Ohio State University.

Desktop simulations of a Boeing 757/767 Electronic Flight Instrumentation System (EFIS) and Control Display Unit (CDU) were used to evaluate the effect of varying the communication method of providing clearance amendments. Amendments were presented either via the traditional speech commands, textual presentation on the display, or graphical presentation on the display. The graphical display was expected to be superior because it was anticipated that the graphical display symbols would be more similar to the pilots' internal representations of the situation. The pilots willingness to accept unacceptable clearance amendments was used as an indication of poor SA. Although the results failed to meet statistical significance, the graphical display tended to reduce the time needed for comprehension and reduce subjective workload ratings. The graphical mode was also rated the highest on a preference scale. However, there was no indication that the mode of presentation affected the detection of unacceptable clearance amendments.

KEYWORDS: air traffic control, aviation (civilian), avionics, cognitive processes, display design, measurement, mental models, performance-based measures, pilot aiding, subjective measures, workload

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33. Companion, M.A. (1994). Situational awareness in emergency management systems: An overview. In R.D. Gilson, D.J. Garland, and J.M. Koonce (Eds.), *Situational awareness in complex systems: Proceedings of a CAHFA Conference* (pp. 283-289). Daytona Beach, FL: Embry-Riddle Aeronautical University Press.

The author describes SA as (p. 284): "the process by which a person extracts, integrates, assesses and responds to task relevant information from the total environment, both spatial and temporal." The author suggests and explains that SA and complex decision making skills might be useful concepts to apply to the training of people involved in emergency management (e.g., a fire chief, hazardous material control, etc.). To accomplish this, it is proposed that the simulation capabilities of desktop computers be used as training aids to familiarize people with the process of responding to emergencies in their domain.

KEYWORDS: cognitive processes, decision making, definition, expertise, training

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34. Cooper, G. (1991, November). Tomorrow's cockpit displays. *Aerospace, 18*(11), 12-14.

The article reviews a lecture by R.A.F. Flt Lts A.C.B. Singer and I.W. McClelland that reviewed aircraft display research conducted at Royal Aerospace Establishment Bedford. One project that is discussed is the development of the Bedford Fast Jet Format (FJF) for head-up displays (HUDs). The FJF was adopted as a standard for the RAF in 1988 and was selected for the European Fighter Aircraft (EFA) program. In discussing the outcome of the development program, it was stated that, "The pitch ladder assists orientation and the FJF as a whole promotes increased mission effectiveness by increasing the pilot's situation awareness and thus reducing his workload" (p. 13). In the description of future programs, the maintenance or improvement of SA is presented as a primary goal.

KEYWORDS: attitude displays, aviation (military), display design, pilot aiding, workload

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35. Corwin, W.H., Probert, A., and Royer, R. (1993). Synthetic terrain imagery for helmet-mounted display. In *Proceedings of the Seventh International Symposium on Aviation Psychology* (Volume 1, pp. 108-114). Columbus: The Ohio State University.

The article reports the results of a study on the effects of displaying a synthetic representation of terrain in the background of a helmet-mounted display on the spatial situation awareness of pilots. The goal was not to create a virtual world, but to determine the minimum necessary visual cues. Several possible formats for presenting the synthetic terrain were compared. The dependent data were subjective assessments from ten pilots who observed the different displays in a F-15 simulator. The preferred format was called the "Mesh" display. The Mesh display (p. 109), "looks as though a large net was laid across the earth."

KEYWORDS: aviation (military), combat simulation, display design, helmet-mounted displays (HMDs), measurement, pilot aiding, subjective measures

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36. Covault, C. (1992, September 14). Russian aircraft marketing threatens power balance. *Aviation Week & Space Technology, 137*(11), 22-23.

In a discussion of Russian attempts to market advanced military aircraft, this article discusses changes in the MiG-29 designed to increase its combat effectiveness and salability. The MiG-29M has already added two multifunction computer displays (MFDs) to the MiG-29 cockpit. In discussing future plans for the aircraft, the article notes (p. 23), "the Russians are examining more complex tactical situation displays, including color callouts, to project on the MFDs. These would provide extremely useful situational awareness data to the pilot preparing for an engagement."

KEYWORDS: aviation (military), display design, pilot aiding

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37. Crabtree, M.S., Marcelo, R.A.Q., McCoy, A.L., and Vidulich, M.A. (1993). An examination of a subjective situational awareness measure during training on a tactical operations simulator. In *Proceedings of the Seventh International Symposium on Aviation Psychology,* (Volume 2, pp. 891-895). Columbus: The Ohio State University.

This paper described an examination of the situation awareness rating technique (SART) for sensitivity to variables which may affect SA. The 10-dimensional version of SART was used, with an added eleventh dimension for overall SA. Variables studied were out-the-window display type (4 "daylight" displays characterized by color of tank, forward looking infrared (FLIR), and Global Positioning Systems (GPS) displays), presence/absence of surface-to-air missile (SAM) sites, approach scenario, and size of target (tank) vulnerable area. Six male subjects were trained for 20 hours on the Simulator for Tactical Operations and Research Measurement (STORM) system; SART measures were solicited twice for each condition, early and late in the training period. SART dimensions showed sensitivity to all variables except size of target's vulnerable area. SART's demand on attentional resources subscales (instability, variability, and complexity) showed sensitivity to more variables than other subscales. Presence/absence of SAMs had the largest effect on these demand subscales. Many of the SART dimensions were sensitive to display type, indicating higher SA when red or black tank displays were used. In addition, SART was sensitive to whether the rating was given early or late in the training period; as expected, subjects indicated far fewer demands on attentional resources when operating the simulator later in the training period.

KEYWORDS: air-to-ground mission, attention, aviation (military), cognitive processes, combat simulation, measurement, SART, subjective measures, training

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38. Craig, J.L., and Purvis, B.D. (1990). B-52 Night vision goggle head-up display development. In *Proceedings - Cockpit Displays and Visual Simulation* (SPIE Proceedings Series Volume 1289, pp 63-71). Bellingham, WA: Society of Photo-Optical Instrumentation Engineers.

This paper describes the implementation of a new night vision display into the US Air Force B-52 Bomber. The display system combined night-vision goggles and a head-up display. As described by the authors (p. 63): "This system displays flight and navigation information onto a combiner glass which is mounted to one of the NVG objective lenses. This allows the pilot to have an 'eyes out' orientation, thereby decreasing communication and workload, and increasing mission safety, situational awareness, and mission effectiveness." The conclusions about the effects of the system are apparently based on the comments of test pilots that used the system during actual night-flight low-level missions in a B-52. The data collection procedure or results are not discussed in enough detail to identify the specific type of tool used in the evaluation.

KEYWORDS: air-to-ground mission, aviation (military), display design, flight test, pilot aiding, subjective measures, workload

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39. Crane, P.M. (1992, April). Theories of expertise as models for understanding situation awareness. In *Proceedings of the Psychology in the Department of Defense Thirteenth Symposium* (Tech. Report No. USAFA-TR-92-2, pp. 148-152). Colorado Springs, CO: US Air Force Academy. (AD-A253006)

The author expresses concern that situation awareness as a term that came out of the operational community lacks clear definition or a clear connection to cognitive theory. No formal definition is offered, but the author suggests that the concept of expertise may provide a good framework for bringing situation awareness into cognitive psychology. Further, the possibility that skilled memory theory could provide the model for the cognitive processing of situation awareness in experts is suggested. If expertise and skilled memory are the correct theoretical background for situation awareness, the author argues that there are three important implications: (1) Situation awareness cannot be considered to be an independent skill or mental ability. Therefore, attempts to directly train situation awareness will be unprofitable. (2) Situation awareness will be domain specific. (3) Simulator-based training for improving situation awareness should emphasize instructional support for encoding and interpreting simulated combat.

KEYWORDS: cognitive processes, definition, expertise, training

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40. Curran, J. (1992). *Trends in advanced avionics.* Ames: Iowa State University Press.

The book describes and reviews many of the major trends in modern avionics in both commercial and military settings. Topics include the trend towards greater subsystem integration, human-centered automation, artificial intelligence aids, new display formats, navigational aids, data-link communications, etc. In many cases, one of the suggested advantages for the modern technology is enhanced SA.

KEYWORDS: aviation (civilian), aviation (military), avionics, data link, display design, pilot aiding

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41. Dalrymple, M.A. (1991, November). *Evaluating airborne warning and control system strategy and tactics as they relate to simulated mission events* (Tech. Report No. AL-TP-1991-0049). Brooks Air Force Base, TX: Armstrong Laboratory. (AD-A242820)

The article discusses the decision-making processes of a Weapons Director (WD) in an AWACS aircraft. The WD is responsible for directing the tactical aircraft in the region as they execute their missions. The first component of the strategy used by effective WDs was described as "developing Situational Awareness" (p. i). The role SA plays was described as follows (p. 7), "To effectively deal with events in an air defense scenario, WDs must maintain an accurate picture of the battle. This picture defines WD awareness of the current situation. Through situational awareness, WDs choose among the tasks competing for their attention and then execute the most important. This decision-making process is more than the application of a predetermined set of priorities.... The choice is a trade-off among what will increase options in the future, what will ease future workload, and what will be the easiest to implement." This description of the decision making process of the WDs appears to be consistent with the notions of recognition-primed decision making (refer to Klein, 1989a, 1989b).

KEYWORDS: aviation (military), cognitive processes, decision making

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42. Deakin, R.S. (1990). Military aircrew head support system. In *Proceedings of the 17th Congress of the International Council of the Aeronautical Sciences - ICAS 1990* (pp. 162-167). Washington, DC: American Institute of Aeronautics and Astronautics.

The article discusses the Military Aircrew Head Support System (MAHSS) being developed in Britain. MAHSS is developing a head support that could be used in combat aircraft. Among other things, the system is intended to aid the pilot in keeping his/her head up during high-g maneuvers. One possible advantage of such a system that is related to SA is (p. 162), "This enables the pilot to maintain a greatly improved level of awareness of his surroundings."

KEYWORDS: aviation (military), pilot aiding

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43. Dickson, D.B., and Hundley, E.L. (1992, July). Avoiding not so friendly fire. *Military Review, 72*(7), 57-64.

Fratricide is the destruction of friendly forces by friendly forces. Fratricide has always occurred durin wars, but this paper argues that the advances in range and lethality of weapons combined with the faster tempo of modern combat make it an even larger problem than it was in the past. This point was supported by the 35 deaths and 72 woundings that occurred during Desert Storm that were due to fratricide. This was a large proportion of the overall casualties that occurred during that war. In May 1991 the Army formed the Combat Identification Task Force to deal with the problem of fratricide. Among the outcomes of this task force's activities was the conclusion that (p. 60), "the inability to maintain situational awareness in combat and the lack of positive target identification capability are the major contributors to fratricide." Situational awareness was defined as (p. 62), "the distributed knowledge of friendly and enemy locations in the context of METT-T (mission, enemy, terrain, troops, and time available)." Along with the Combat Identification Task Force, the Fratricide Prevention Task Force was formed to determine how to integrate fratricide prevention measures into the Army. The two task forces have issued recommendations that involve changes in doctrine, acquisition of new material, and changes in training to increase SA and reduce the potential for fratricide.

KEYWORDS: battlefield SA, definition, fratricide, target identification, training

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44. Dornheim, M.A. (1986, June 23). Crew situational awareness drives avionics developments. *Aviation Week & Space Technology, 124*(25), 114-116.

Dornheim discusses efforts to enhance fighter crew situational awareness with improved avionics on the Air Force Advanced Tactical Fighter. Avionics which incorporate coordinated sensors, order large quantities of information, and use displays keyed to natural human perception (such as sound) are being developed. Dornheim states that key challenges include finding targets while minimizing emissions, identifying friend or foe, and displaying this information. Future "supercockpit" features under consideration include three dimensional presentation of information, control by eye/voice, rapid control/display reconfiguration, and monitoring of pilot condition. Dornheim also briefly discusses a Stereographics Corporation three-dimensional display and helmet mounted displays.

KEYWORDS: aviation (military), avionics, display design, helmet-mounted displays (HMDs), pilot aiding

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45. Dyck, J.L., and Gilson, R.D. (1994). Situation awareness in marginal weather conditions: Do graphical presentations help? In R.D. Gilson, D.J. Garland, and J.M. Koonce (Eds.), *Situational awareness in complex systems: Proceedings of a CAHFA Conference* (pp. 251-259). Daytona Beach, FL: Embry-Riddle Aeronautical University Press.

In this project, SA is seen as a contributor to the decision making process of a pilot faced with marginal weather conditions. For most General Aviation pilots, weather information is accessed through a textually-based system. The authors suggest that a graphically-based system might improve the SA for weather conditions. This was tested in an experiment. The flight decisions and rationale of General Aviation pilots that were provided with either textual or graphical weather information were compared to the decisions of an expert group of pilots. The decision and reasoning of the subject pilots did differ from the expert pilots, showing an effect of expertise. However, only a few marginal effects were associated with the format of the weather information. Nevertheless, the authors contend that the proper use of graphical weather information may yet prove to be of value, and make suggestions for future research based on their experiences with this project.

KEYWORDS: aviation (civilian), cognitive processes, decision making, display design, expertise

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46. Edens, E.S. (1991, April). *Individual differences underlying pilot cockpit error* (Tech. Report No. DOT/FAA/RD-91-13). Washington, DC: US Department of Transportation. (AD-A236107)

This paper is a doctoral dissertation. The question studied is whether personality, attitudes, and cognitive ability impact the likelihood of pilot error. Edens defines SA as "the accurate perception of the factors and conditions affecting the aircraft and the flight crew" (p.7). She predicted that SA, psychological stress, and hazardous thought patterns are cognitive processes which act as mediating variables between individual differences (to include achievement motivation, vulnerability, and extroversion) and pilot error. A model is presented outlining this relationship. Student helicopter pilots (n=312) served as subjects in this study. Measures of pilot error were made by instructor pilots and evaluation pilots. Results showed that only pilot situational awareness and psychological stress levels predicted the frequency of cockpit error. Individual differences as predictors were a disappointment.

KEYWORDS: cognitive processes, definition, helicopter, individual differences, measurement, performance-based measures, pilot error, subjective measures

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47. Emerson, T.J., Reising, J.M., and Britten-Austin, H.G. (1987). *Workload and Situation awareness in future aircraft* (SAE Technical Paper Series No. 871803). Warrendale, PA: Society of Automotive Engineers.

This article discusses the potential development of an artificially intelligent Electronic Crewmember (EC) for future generations of fighter aircraft. The need for real-time input on the pilot's state of workload and SA into the EC is highlighted. Physiological indices and performance profiles are discussed as means of meeting this need. The authors address the issue of defining SA (p. 4): "Situation awareness (SA) can be defined as the crew's knowledge of both the internal and external states of the aircraft, as well as the environment in which it is operating." Among the ways that EC will help the pilot maintain SA are the off-loading of many monitoring responsibilities, fusing data prior to presentation, allowing high-level command communication with aircraft systems, mission preview, and real-time reallocation of tasks.

KEYWORDS: aviation (military), avionics, decision aiding, definition, measurement, performance-based measures, physiological measures, pilot aiding, workload

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48. Emery, C.D., and Holding, D.H. (1993). Practice effects on the Wombat device. In *Proceedings of the Seventh International Symposium on Aviation Psychology* (Volume 1, pp. 394-397). Columbus: The Ohio State University.

This research investigated SA as a generic skill. A testing device called the Wondrous Original Method for Basic Airmanship Testing (WOMBAT) was used as the criterion. The WOMBAT is a desktop testing device that presents a tracking task along with a set of selected time-shared tasks. Two studies were conducted. In the first study, WOMBAT was used to assess a group of 20 commercial airline pilots. Ratings of each of the pilots on basic aviation skills and cockpit resource management skills were collected from the pilots' fleet chief pilots. Also, records of flight training checks were assessed. Correlation among all of the measures found little relationship between the WOMBAT measure and any of the other measures of flying proficiency. In the second study, the WOMBAT performance of pilots was compared to that of college students. Differences in the learning curves of the two groups were observed. In the discussion the authors present possible reasons for the lack of association between WOMBAT performance and the measures of flight proficiency. They also suggest that the learning curve differences observed in study two might be a useful selection tool.

KEYWORDS: aviation (civilian), cognitive processes, expertise, individual differences, measurement, performance-based measures

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49. Endsley, M.R. (1987). The application of human factors to the development of expert systems for advanced cockpits. In *Proceedings of the Human Factors Society 31st Annual Meeting* (Volume 2, pp. 1388-1392). Santa Monica, CA: Human Factors Society.

This article discusses the potential impact of expert systems in advanced cockpits. Endsley suggests that evaluation of automation incorporating expert systems must include measurement of four attributes: workload, situation awareness, performance, and acceptance. Regarding SA, she specifically mentions the Situation Awareness Global Assessment Technique (SAGAT) as a potential measure of the effect of a new cockpit system on SA.

KEYWORDS: aviation (military), avionics, measurement, memory probe measures, pilot aiding, SAGAT, workload

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50. Endsley, M.R. (1988a). Design and evaluation for situation awareness enhancement. In *Proceedings of the Human Factors Society 32nd Annual Meeting* (Volume 1, pp. 97-101). Santa Monica, CA: Human Factors Society.

This paper defines situation awareness as (p. 97), "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future." Endsley uses this definition consistently throughout her work. She places SA in the framework of human information processing models with a graphic "aircrew decision model," and with a figure which depicts information processing, memory structures, and attention and decision making, entitled "mechanisms of situation awareness." These structures are discussed in detail. Thirteen design guidelines are listed for use in maximizing the SA of a system, and then the Situation Awareness Global Assessment Technique (SAGAT), a technique for evaluating pilot situation awareness in simulators, is described. Endsley states that the primary limitation of SAGAT is that the simulation must be halted to collect the data, and then lists several advantages of SAGAT.

KEYWORDS: attention, aviation (military), cognitive processes, decision making, definition, design guidelines, measurement, memory probe measures, pilot aiding, SAGAT

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51. Endsley, M.R. (1988b). Situation awareness global assessment technique (SAGAT). In *Proceedings of the IEEE 1988 National Aerospace and Electronics Conference - NAECON 1988* (Volume 3, pp. 789-795). New York: Institute of Electrical and Electronics Engineers.

In this paper, Endsley mainly focuses on the SAGAT methodology, and discusses studies undertaken to validate the technique. The definition of SA is taken a step further, introducing the concept of SA zones of interest, which are concentric rings representing areas of immediate, intermediate, and long-term interest to the pilot. SA measurement is considered from a viewpoint where the goal is to evaluate whether SA is better in one system than in another. Subjective, physiological, and questionnaire methods of measuring SA are critiqued, and then Endsley presents the SAGAT approach in detail. A paper and pencil version of SAGAT was employed in a 1987 pilot study; this work is discussed, along with another study in which SAGAT was used. Endsley concludes by projecting future growth and utilization of SAGAT.

KEYWORDS: definition, measurement, memory probe measures, physiological measures, questionnaire/survey data, retrospective measures, SAGAT, subjective measures

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52. Endsley, M.R. (1990a, April). A methodology for the objective measurement of pilot situation awareness. In AGARD-CP-478, *Situational Awareness in Aerospace Operations* (pp. 1-1 to 1-9). Neuilly Sur Seine, France: Advisory Group for Aerospace Research & Development. (AD-A223939)

This paper begins with a listing of areas where research is ongoing in situation awareness; sensor technology, advanced displays and controls, and automation of pilot tasks are included in this list. Endsley states that researchers have been hampered by lack of a common, consistent definition of SA and by the lack of an objective technique for evaluating competing design concepts. There is a comprehensive section which breaks down the elements of her proposed definition of SA, and a discussion on cognitive foundations of SA. The SAGAT procedure is described, along with two studies utilizing the technique, one on memory decay and one dealing with frequency and duration of halts to the simulation when SAGAT data is being collected. This paper concludes by suggesting research in the areas of design, training, and construct exploration.

KEYWORDS: aviation (military), cognitive processes, combat simulation, definition, measurement, memory probe measures, performance-based measures, SAGAT

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53. Endsley, M.R. (1990b). Predictive utility of an objective measure of situation awareness. In *Proceedings of the Human Factors Society 34th Annual Meeting* (Volume 1, pp. 41-45). Santa Monica, CA: Human Factors Society.

This paper describes results of a study undertaken to compare performance of pilots in a simulated air-to-air engagement with objective SAGAT measures of SA. Performance was measured by air-to-air kills and losses during the simulation, which pitted two teams of pilots against each other with specific (but different) goals and rules of engagement on each side. The study found that one team was limited by the rules of engagement and by equipment and thus was less able to take advantage of its SA in terms of kill ratio. The other team displayed a significantly better likelihood of later killing an aircraft when they had SA of that aircraft. Lower SA did not always accompany poor performance; pilots possibly were aware that their SA was poor and acted more conservatively, according to Endsley. She also proposed reasons as to why there were differences in SA among pilots. Endsley concludes that the predictive relationship between SA as measured by SAGAT and pilot performance is supported by this study.

KEYWORDS: air-to-air mission, aviation (military), cognitive processes, combat simulation, decision making, measurement, memory probe measures, performance-based measures, SAGAT, team decision making, team SA

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54. Endsley, M.R. (1991a). *Situation awareness in an advanced strategic mission* (Tech. Report No. AL-TR-1991-0083). Wright-Patterson Air Force Base, OH: Air Force Systems Command. (AD-B161348)

This report includes extensive discussion of the issues associated with situation awareness. As in other papers, the author defines situation awareness as (p. 7), "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future." The author is careful to distinguish situation awareness from decision making. Situation awareness is considered to be the input to the decision making process. The author also extends the definition of situation awareness to take into account crew situation awareness (p. 9): "Comprehensive crew SA can be conceived of as 'the degree to which every crew member possesses the SA required for his position.'" The discussion of theoretical underpinning of situation awareness emphasizes memory processes (including sensory memory, working memory capacity, knowledge in long-term memory, etc) and attention. Based on this discussion, 13 recommendation for system design to optimize situation awareness are presented and the possible role of individual differences is discussed. Potential situation awareness measurement techniques are discussed. Subjective ratings are considered problematic because the crewmember may not realize that there is important information that he is unaware of, and also his ratings may be biased by the outcome of the mission. Physiological techniques are considered desirable, but unproven. Questionnaires are suspect due to the limitations of human memory. The author argues that the best measurement approach is represented by the Situation Awareness Global Assessment Technique (SAGAT). SAGAT involves randomly stopping a simulated mission and asking a series of questions to ascertain the state of the crewmembers situation awareness. The design of a SAGAT analysis of a strategic mission is described in great detail. No data are presented.

KEYWORDS: air-to-ground mission, aviation (military), definition, design guidelines, individual differences, measurement, memory probe measures, physiological measures, questionnaire/survey data, retrospective measures, SAGAT

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55. Endsley, M.R. (1991b). Situation awareness in dynamic systems. In *Designing for Everyone: Proceedings of the 11th Congress of the International Ergonomics Association* (Volume 1, pp. 801-803). Paris, France: Taylor & Francis.

This paper, along with 4 other SA related papers presented at the Congress, were reprinted in Taylor (1991) and is reviewed under that listing.

KEYWORDS: measurement, memory probe measures, SAGAT

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56. Endsley, M.R. (1993a). Situation awareness and workload: Flip sides of the same coin. In *Proceedings of the Seventh International Symposium on Aviation Psychology* (Volume 2, pp. 906-911). Columbus: The Ohio State University.

The author examines the issue of the relationship between mental workload and situation awareness. Her hypothesis is stated as, "SA and workload, although inter-related, are hypothesized to be essentially independent constructs." The concepts are assumed to be inter-related because situation awareness involves mental information processing and this contributes to mental workload. So, in many environments, the investment of additional mental workload may be associated with increasing situation awareness. However, a person operating in a familiar, well-understood environment might have excellent situation awareness combined with very low mental workload. Or alternatively, a person may be working very hard in an attempt to understand a situation, but fail. The relationship between workload and situation awareness was tested by comparing subjective workload ratings to a situation awareness metric collected during simulated air combat. The SWAT procedure was used to assess mental workload, and SAGAT was used to assess situation awareness. Six experienced former military pilots served as the subjects. Overall, there was no correlation between SWAT ratings and SAGAT scores, supporting the hypothesis. However, evaluation of the individual pilot data found that two of the pilots correlated higher workload with lower situation awareness. Despite these two pilots showing a relationship, the overall conclusion was that the hypothesized independence was supported. The author also suggests that this independence might be inconsistent with attempts of some metric techniques (e.g., SART) to combine elements of both concepts.

KEYWORDS: aviation (military), cognitive processes, combat simulation, measurement, memory probe measures, SAGAT, SART, subjective measures, workload

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57. Endsley, M.R. (1993b). A survey of situation awareness requirements in air-to-air combat fighters. *The International Journal of Aviation Psychology, 3*, 157-168.

The author reiterates her previous definition of SA (see Endsley, 1988a). The paper then describes a procedure for determining the specific SA needs consistent with the SA definition for a given task domain. Air-to-air combat is utilized as an example domain to illustrate the procedures. The procedure consists of three steps: One, the author conducted unstructured interviews with subject-matter experts to determine their thoughts about the nature of SA and its relationship with mission performance. Two, the author conducted a goal-directed task analysis by observing simulated air-to-air combat. The observations were used to identify primary goals, subgoals, and SA needs for the various segments of air-to-air combat. These data were represented in tree-diagrams that were then critiqued by subject-matter experts. Third, based on the results of the first two phases, a structured questionnaire was constructed and distributed to another set of subject-matter experts to elicit criticality judgments. The results of these judgments are tabulated in the paper. This paper will be especially interesting for researchers engaged in evaluating SA in an air-to-air domain. However, the procedure could also be used in other domains to specify SA needs.

KEYWORDS: air-to-air mission, aviation (military), cognitive processes, definition, expertise, measurement, questionnaire/survey data, subjective measures

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58. Endsley, M.R. (1994a). Situation awareness in dynamic human decision making: Theory. In R.D. Gilson, D.J. Garland, and J.M. Koonce (Eds.), *Situational awareness in complex systems: Proceedings of a CAHFA Conference* (pp. 27-58). Daytona Beach, FL: Embry-Riddle Aeronautical University Press.

In this paper, Endsley presents the most thorough review of her theoretical views on SA (to date). As a definition for SA, the definition from Endsley (1988a) is adopted. She suggests that SA will be a vital theoretical construct for understanding and improving performance in a wide variety of operational settings. The theoretical approach selected for addressing SA is James Reason's concept of a framework model. In this approach the goal is to synthesize information from a wide variety of setting and theories into a good descriptive model. As background for her framework model, Endsley states that (p. 34): "In combination, the mechanisms of short term sensory memory, perception, working memory and long term memory form the basic structures on which SA is based." The contribution and interaction of these processes are described. Attention is also discussed as an important, limiting component of SA (p. 36): "Because the supply of attention appears to be limited, improvements in SA on some elements may mean decrements in SA on others once the limit is reached. And this limit may occur rather quickly in complex environments." The paper also discusses the possible roles of mental models in SA, the role of SA in errors, and how the SA concept can be extended to team environments. The paper concludes with a discussion of future direction for SA research in human-machine interface design, training, individual differences, and theoretical constructs.

KEYWORDS: attention, cognitive processes, decision making, definition, expertise, mental models, team SA, training, workload

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59. Endsley, M.R. (1994b). Situation awareness in dynamic human decision making: Measurement. In R.D. Gilson, D.J. Garland, and J.M. Koonce (Eds.), *Situational awareness in complex systems: Proceedings of a CAHFA Conference* (pp. 79-97). Daytona Beach, FL: Embry-Riddle Aeronautical University Press.

This article discusses the potential uses of several approaches for measuring SA. As a definition for SA, the definition from Endsley (1988a) is adopted. Physiological measurement is seen as having limited usefulness (p. 81): "These techniques will allow researchers to determine if elements in the environment are perceived and processed by subjects, but do not allow a determination of how much information remains in memory, if the information is registered correctly in the mind, or what comprehension the subject has of those elements." Performance measures are divided into three main categories: Global measures, External task measures, and Imbedded task measures. All are seen as having the advantages of being objective and usually non-intrusive to assess. But, global measures of performance are seen as having problems with diagnosticity and sensitivity. External task measures are criticized as being very intrusive and based on questionable assumptions. Imbedded task measures suffer from being overly focused on a small subset of the operator's subtasks, and potentially insensitive to changes in SA elsewhere in the system. The next category of SA measurement is subjective measures, which is divided into two subcategories: Self-rating, and Observer-rating. Endsley identifies several sources of contamination of SA self-ratings (e.g., SART and SA-SWORD), and suggests that (p. 83), "subjective self-ratings of SA most likely convey a measure of the subjects' confidence level regarding that SA." It is suggested that observer-ratings of SA might be limited by the observers' lack of access to the subjects' concept of the situation. The final category of SA measurement is Questionnaires, which is subdivided into: Post-test, On-line, and Freeze Technique. Questionnaires are seen as good for obtaining detailed information about the subject's SA, but the post-test version is seen as being too limited by tendencies "to over generalize, over summarize and over rationalize" (p. 85) about past mental events. On-line vocalization was seen as too intrusive. As a solution to the difficulties with the post-test or on-line approaches, the use of a freeze technique (such as SAGAT) was advocated. In a freeze procedure, the simulation is frozen at randomly selected moments and the subject answers questions about their current perceptions of the situation. A potential difficulty with this approach is the perceived intrusiveness of stopping the simulation. Two studies are reviewed that suggest that the SAGAT technique can be sensitive without be intrusive.

KEYWORDS: definition, measurement, memory probe measures, performance-based measures, physiological measures, questionnaire/survey data, retrospective measures, SAGAT, SART, SA-SWORD, subjective measures, verbal protocols

60. Fracker, M.L. (1988a). A schema-based model of situation awareness: Implications for measuring situation awareness. In *Second Annual Workshop on Space Operations, Automation, and Robotics - (SOAR '88)* (Tech. Report No. NASA-CP-3019, pp. 227-231). Washington, DC: National Aeronautics and Space Administration.

The author is primarily concerned with addressing two issues: the definition of SA, and modeling how SA is maintained. To define SA, he starts by addressing the issue of defining a situation (p. 227): "I define a situation to be a set of processes that control events in the environment.... A situation, then, can be defined at various levels of abstraction. At the highest level, the situation might be defined in terms of the goals of the human participants. At the lowest level, the situation may be defined in terms of the momentary states of objects in the environment. In between these two extremes, the situation may be defined in terms of the organizations, functions, or processes that translates goals into states." SA is then defined in terms of this viewpoint of a situation (p. 227), "Situation awareness, therefore, can be defined partly as the knowledge that results when attention is allocated to the environment at one or more levels of abstraction." The model for understanding the cognitive processes of SA is based upon the implications of schema theory. The issues of how the schema control the allocation of attention and are influenced by the limits of working memory capacity are also discussed. One negative aspect of the use of schema is said to be the propensity for schema-based information processing to be affected by biases. The author suggests that the fact that SA represents a mixing of prior knowledge and current perception produces challenges for any memory based measurement technique. As a final conclusion, the author states (p. 230), "the model suggests that measuring the load on working memory imposed by situation assessment may be as important as measuring SA itself." In other words, high levels of mental workload are seen as a threat to the maintenance of good SA.

KEYWORDS: attention, cognitive processes, expertise, measurement, memory probe measures, retrospective measures, schema, subjective measures, workload

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61. Fracker, M.L. (1988b). A theory of situation assessment: Implications for measuring situation awareness. In *Proceedings of the Human Factors Society 32nd Annual Meeting* (Volume 1, pp. 102-106). Santa Monica, CA: Human Factors Society.

In this paper, Fracker defines SA as "...the knowledge that results when attention is allocated to a zone of interest at a level of abstraction." He goes on to explain this definition in detail, and then describes a model of SA based on knowledge structures, or "schemata." He proposes that pilots recognize patterns of sensory information and apply established schemata to fill in the details of the situation. If an appropriate schema is not available or is not identified, the load on the pilot's working memory is increased greatly by the alternative processes required. Fracker discusses five cognitive biases inherent in this schemata theory. Memory-probe measures of SA and some problems associated with them are reviewed. In closing, Fracker proposes a secondary memory span task for measuring the load on working memory associated with SA.

KEYWORDS: attention, cognitive processes, definition, expertise, measurement, memory probe measures, retrospective measures, schema, subjective measures

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62. Fracker, M.L. (1989). Attention allocation in situation awareness. In *Proceedings of the Human Factors Society 33rd Annual Meeting* (Volume 2, pp. 1396-1400). Santa Monica, CA: Human Factors Society.

The paper presents research investigating the impact of limited attentional capacity on situation awareness and the utility of memory probes as situation awareness metrics. Subjects were given a "God's-eye" view of a simulated air battle involving one aircraft under their control and a wing-man. An additional five aircraft were always present, but the proportion of enemies to neutral was varied. Also, on some trials the identity of the other aircraft could change during the trial. Based on the assumption that attentional capacity is limited, it was predicted that situation awareness would be unequally distributed over the different aircraft types. In specific, spatial localization of neutrals was expected to be less accurate than enemies. However, since aircraft identity presumably had to be known prior to allocating attention, it was expected that identifying identity would be unaffected by the Neutral/Enemy distinction. These hypotheses were tested via memory probe situation awareness metrics. At random times, the trial stopped and subjects were asked to identify one aircraft (Friend, Enemy, or Neutral) and show the correct location for another aircraft. Results were consistent with the expected allocation of attention. The author concluded that the results supported the viability of memory probes as an approach for situation awareness assessment.

KEYWORDS: attention, cognitive processes, measurement, memory probe measures, target identification

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63. Fracker, M.L. (1990, April). Attention gradients in situation awareness. In AGARD-CP-478, *Situational Awareness in Aerospace Operations* (pp. 6-1 to 6-10). Neuilly Sur Seine, France: Advisory Group for Aerospace Research & Development. (AD-A223939)

This paper describes a series of four studies undertaken with the objective of supporting a theory of a limited supply of attention by demonstrating reallocation of that attention. Specifically, he proposes that if there is a finite amount of attention, then it will most likely be reallocated to threatening targets (enemy aircraft) as the total number of aircraft in a simulation increases. Fracker found support for this theory. He used spatial awareness and friend/foe/neutral probe reaction time as measures of attention allocation. He describes a phenomenon whereby we tend to ignore neutral information, in this case represented by neutral aircraft, attending instead to targets which are threatening to or supportive of our own mission.

KEYWORDS: attention, cognitive processes, measurement, memory probe measures

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64. Fracker, M.L. (1991a, October). *Measures of situation awareness: An experimental evaluation* (Tech. Report No. AL-TR-1991-0127). Wright-Patterson Air Force Base, OH: Armstrong Laboratory. (AD-A262732)

This report describes a complex set of studies conducted with several goals in mind. Mainly, Fracker sought to gather reliability data and establish criterion and construct validity for a set of SA measures. The measures, both implicit and explicit, were designed to support a multiple resource theory of processing. Three studies were conducted. Fracker's two hypotheses were (1) object locations and identities are maintained in separate working memories, and (2) these two working memories have separate processing resources, so that increasing processing difficulty in one has no effect on the other. Subjects viewed several objects on a screen, objects color coded as to whether they were friend, foe, or neutral. The implicit measure was "envelope sensitivity," a measure of how well subjects completed a task involving destroying the enemy targets on the screen. The explicit measures were derived by freezing the screen during the task and asking probe questions about one of the objects' identity or location. The screen also contained "death zones" which subjects had to avoid, creating another measure of performance called avoidance failures. Fracker looked at test-retest reliability by running the subjects over two separate sessions. The reliability measures proved inconclusive, in that none of the measures were highly reliable In assessing criterion validity, subjects' "kill probability" was the criterion measure against which identity and location probe measures were compared. Identity accuracy and latency validity coefficients were small, and the author attributes this to the low reliability. Object location error was not a good predictor. The best predictor was the avoidance failure measure, which is described as more of a workload measure than a SA measure. In examining construct validity via a "separate resources" theory, Fracker found that spatial and verbal capabilities combined to overload working memory. He therefore concludes that either the validity of these measures should be questioned, or individuals possess just one common processing resource.

KEYWORDS: attention, cognitive processes, implicit measures, measurement, memory probe measures, multiple resource theory, reliability

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65. Fracker, M.L. (1991b, October). *Measures of situation awareness: Review and future directions* (Tech. Report No. AL-TR-1991-0128). Wright-Patterson Air Force Base, OH: Armstrong Laboratory. (AD-A262672)

In this paper, Fracker discusses definitions and examples of reliability and validity (content, criterion, and construct) as they pertain to measurement of SA. The author then examines several types of SA measures which have been used in previous research, reviewing how various authors employed these measures and assessing them in terms of reliability and the three types of validity mentioned above. Explicit, implicit, and subjective rating measures are all treated in this fashion. This is a good paper to consult if one is considering how to implement an SA metric in any kind of laboratory or field study.

KEYWORDS: implicit measures, measurement, memory probe measures, reliability, retrospective measures, review paper, subjective measures

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66. Fracker, M.L., and Davis, S.A. (1991, October). *Explicit, implicit, and subjective rating measures of situation awareness in a monitoring task* (Tech. Report No. AL-TR-1991-0091). Wright-Patterson Air Force Base, OH: Armstrong Laboratory. (AD-A262702)

Subjects monitored a display on which six colored objects moved about on a grid. They watched for an unpredictable flash of any object (an embedded signal detection measure of situation awareness). Occasionally, the display would freeze and the objects would disappear. Subjects would then answer memory probes concerning the color and location of selected objects. Subjective ratings were also collected. Results suggested that the flash detection and color memory probes were effective situation awareness metrics. The location probes seemed to be insensitive measures of situation awareness. The subjective ratings appeared to be useful, but the authors cautioned that (p. 23), "subjective measures may be measuring subjects' rational inferences about their SA or workload."

KEYWORDS: implicit measures, measurement, memory probe measures, performance-based measures, subjective measures, workload

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67. Fracker, M.L., and Vidulich, M.A. (1991). Measurement of situation awareness: A brief review. In *Designing for Everyone: Proceedings of the 11th Congress of the International Ergonomics Association* (Volume 1, pp. 795-797). Paris, France: Taylor & Francis.

This paper, along with 4 other SA related papers presented at the Congress, were reprinted in Taylor (1991) and is reviewed under that listing.

KEYWORDS: implicit measures, measurement, memory probe measures, retrospective measures, subjective measures

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68. Fulghum, D.A. (1993, February 8). Night-fighting CAS force gains preliminary approval. *Aviation Week & Space Technology, 138*(6), 52-54.

The article discusses potential modifications to F-16 aircraft to enhance their effectiveness in nighttime ground- attack missions. As an alternative to a head-steered Forward-Looking Infrared (FLIR) system the Air Force suggested upgrading F-16s already equipped with the Low-Altitude Navigation and Targeting Infrared (LANTIRN) system. In part, the suggestion appears to be a cost-savings move. But, it is also suggested that (p. 54), "The F-16's modifications - including ... night vision goggles and global positioning system (GPS) - give the ground attack pilot better situational awareness."

KEYWORDS: air-to-ground mission, aviation (military), pilot aiding

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69. Fulghum, D.A. (1993, July 5). Major changes planned for wild weasel force. *Aviation Week & Space Technology, 139*(1), 40-41.

The article describes proposed future developments for military aircraft, such as the F-4, assigned to the Suppression of Enemy Air Defenses (SEAD) mission. Two proposed changes are expected to increase the SA of the SEAD aircraft crew. The first is communications with sensors from other aircraft or satellites. The second proposed change is the addition of a tactical situation display for presenting the information.

KEYWORDS: air-to-ground mission, aviation (military), avionics, data fusion, data link, display design, pilot aiding

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70. Fulghum, D.A. (1993, August 23). Talon Lance gives aircrews timely intelligence from space. *Aviation Week & Space Technology, 139*(8), 70-71.

The article discusses the Talon Lance program. This program is aimed at developing on-board computer analysis capabilities to analyze in real-time the intelligence information from satellites, other warplanes, etc. Currently, such information is hours old and available only at takeoff with in-flight updates via radio. The Talon Lance system will present a filtered version of all of this information to the pilot during the mission. Among the rationale for justifying the system was "extending situational awareness" (p. 71).

KEYWORDS: aviation (military), avionics, data fusion, data link, pilot aiding

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71. Furness, T.A. (1986). The super cockpit and its human factors challenges. In *Proceedings of the Human Factors Society 30th Annual Meeting* (Volume 1, pp. 48-52). Santa Monica, CA: Human Factors Society.

This article presents the design philosophy behind the development of the Super Cockpit research program. The Super Cockpit was envisioned as a generic crew station that would use virtual visual, auditory, and tactile displays to exploit the full perceptual capabilities of the human pilot. Among the anticipated advantages of the Super Cockpit was one directly related to SA (p. 51), "the display medium truly offers a port for the avionics to communicate a spatial awareness to the pilot in all directions and in three dimensions." Among the challenges posed to the human factors community by the Super Cockpit was (p. 52), "How can the level of situation awareness conveyed to the pilot be assessed?"

KEYWORDS: 3-D audio displays, display design, helmet-mounted displays (HMDs), pilot aiding

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72. Garland, D.J., and Hopkin, V.D. (1994). Controlling automation in future air traffic control: The impact on situational awareness. In R.D. Gilson, D.J. Garland, and J.M. Koonce (Eds.), *Situational awareness in complex systems: Proceedings of a CAHFA Conference* (pp. 179-197). Daytona Beach, FL: Embry-Riddle Aeronautical University Press.

This article covers much of the same ground as Hopkin (1994) in relating situation awareness to air traffic control. However, it goes into more detail in discussing proposed changes in the automation supporting air traffic controllers and the possible effects on the air traffic controller's SA.

KEYWORDS: air traffic control, cognitive processes, individual differences, mental models, training

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73. Gibson, C.P., and Garrett, A.J. (1990, April). Towards a future cockpit - The prototyping and pilot integration of the mission management aid (MMA). In AGARD-CP-478, *Situational Awareness in Aerospace Operations* (pp. 7-1 to 7-9). Neuilly Sur Seine, France: Advisory Group for Aerospace Research & Development. (AD-A223939)

This paper was presented at the 1989 AGARD meeting on Situational Awareness in Aerospace Operations. Gibson and Garrett define SA as (p. 7-1) "...the pilot's overall appreciation of his current 'world,'...[implying] both sensory processing and inferencing [from] previous knowledge and experience." Because SA is a Gestalt-type concept, "greater than the sum of the parts," the authors propose that it is difficult to measure and "limited in its utility as a tool to predict performance" (p. 7-1). The paper describes the mission management aid (MMA), which in essence provides the pilot with a plan for action based on the environmental and aircraft information available. The pilot may accept or reject this plan, or may query the MMA for further underlying information. The prototype MMA is designed to operate in an air-to-ground role, and to interact with other nearby MMAs. The paper also details how the MMA design process was accomplished. Rather than top-down or bottom-up design, a flexible mixture of the two was employed with a heavy emphasis on incorporating human factors aspects early in the design process.

KEYWORDS: air-to-ground mission, attention, aviation (military), avionics, cognitive processes, data fusion, definition, pilot aiding

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74. Goldworm, M., and Millar, J. (1993, September). Fast mapping for cockpit displays. *Defense Electronics, 25*(10), 42-44.

The authors suggest that dynamic, flexible map displays would be an effective means for improving pilot SA. They contrast two technological approaches for achieving this goal. Many map displays are based on bit-mapped images generated by scanning paper charts. This can produce a high resolution image in a familiar format and enjoys certain technological advantages. However, the authors suggest that an alternative approach based on the Vector Product Format (VPF) may have functional advantages because the flexible way the map data is coded allows for more flexibility in display formats. On the other hand, the VPF approach currently faces technological challenges. The authors conclude (p. 44), "Both the right software and processing hardware are necessary to achieve the performance and flexibility required of modern weapon systems. Designers of mapping and situational awareness systems, whether in the cockpit or on the ground, have to understand these issues and plan for them in system development efforts."

KEYWORDS: aviation (military), display design, pilot aiding

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75. Goodson, W.L., Walters, R.V., and Stites, R.L. (1990). *An artificial neural network for the estimation of tactical situation awareness* (Tech. Report No. USAFSAM-TP-90-9). Brooks Air Force Base, TX: Human Systems Division. (AD-B146397)

The goal of this research is to establish a framework artificial neural network (ANN) from which to develop an SA training device (in the Phase II SBIR). Goodson et al. have proposed a conceptual framework which breaks the SA construct down into a progression of tactical data vectors (tactical environment data *e*, aircraft environment data *i*, pilot SA or knowledge *k*, tactical response *a*, and workload *w*). The domain chosen for development of this ANN is situational awareness in combat fighter tactics, limited to a 2v2 visual identification intercept training flight. Four subnetworks make up this ANN model, one each modeling *Ps* (probability of success), *i*, *k*, and *w*, two of which are fed by a common gated dipole field. The authors proposed that *Ps*, which is a composite of probability of kill and probability of survival, is critical to understanding SA and workload in this fighter environment. Indeed, in the air combat simulation run, the *Ps* measure was the most sensitive to changes in the tactical situation, and it correlated highly with the value of *k*. Goodson et al. describe other potential uses for an SA ANN. Demonstration software code and scenario data are included in the appendices.

KEYWORDS: air-to-air mission, aviation (military), combat simulation, modeling, training

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76. Gordon, B. (1993). Cockpit attention and task management: Situation awareness in the tactical fighter. In *Proceedings of the Seventh International Symposium on Aviation Psychology* (Volume 2, pp. 912-917). Columbus: The Ohio State University.

The article describes the development and implementation of a cockpit resource management (CRM) course for single seat tactical aircraft flown by the United States Air Forces in Europe (USAFE). The course was called Cockpit Attention and Task Management (CATM). CATM was developed as a response for accident investigations that suggested that every serious operational mishap involved a deficiency in attention management. CATM was designed to teach attention management. Attention management was defined as (p. 913), "The ability to prioritize tasks, recognize mission demands, and maintain situation awareness in the dynamic flight environment." According to the author, attention management became synonymous with SA within the program. The attention management training was conducted as workshops with USAFE pilots. Although the author reports that the program was well received, there is no objective data to support its effectiveness. The author suggests that better metrics for measuring the effectiveness of such human factors programs are needed.

KEYWORDS: attention, aviation (military), cockpit resource management (CRM), cognitive processes, definition, pilot error, training

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77. Granda, T.M., McClure, D.H., and Fogarty, J.W. (1991). The development of an altitude awareness program: An integrated approach. In *Proceedings of the Human Factors Society 35th Annual Meeting* (Volume 1, pp. 47-51). Santa Monica, CA: Human Factors Society.

The research was not directly presented as a SA project, but the concept of awareness played a vital role in the project. A rising trend of altitude deviations had been detected in commercial aviation. This encouraged the development of the Altitude Awareness Program by USAir and the Air Line Pilots Association. The paper reviews two aspects of this program: proposed cockpit procedural changes to increase crew awareness of assigned and actual altitude, and an altitude awareness study to examine the causes of altitude deviations. The study consisted of requesting approximately 5500 USAir pilots to voluntarily fill out a questionnaire developed by subject-matter experts to identify the causes and context of observed altitude deviations in actual airline operations. As of the writing of this paper a total of 97 incident reports had been submitted. Among the findings, a large percentage of the altitude deviations involved failure to follow the new cockpit procedures. Typically, this involved a lack of communication among cockpit members. The paper serves as an example of research within an operational setting, the importance of communication among crew members to foster shared awareness of the aircraft situation, and the utility of retrospective surveys as a data source.

KEYWORDS: aviation (civilian), measurement, performance-based measures, questionnaire/survey data, retrospective measures, subjective measures, team SA

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78. Gravelle, M.D. (1991). Chief scientist report special: Technical inquiry report on situation awareness. *CSERIAC Gateway, 2*(2), 14.

Gravelle discusses some of the difficulties encountered in trying to extend the SA concept from its most common aviation setting to the domain of command, control, and communication (C3) environments. The analysis suggested that the two main problems were the lack of a common definition and the lack of accepted metric techniques. In regard to the definition issue, the author suggests (p. 14): "Generally speaking, SA describes an operator's internal representation or mental model of the immediate surroundings and a certain zone of interest." In regard to the measurement issue, the author expresses concern about whether metrics that have primarily been designed to assess SA in an air combat environment will be appropriate to C3 settings. In particular, the author argues that the SA concept will need to include awareness of the other team members.

KEYWORDS: definition, measurement, team SA

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79. Griffin, G.R. (1988). Predicting air combat maneuvering (ACM) performance. In AGARD-CP-458, *Human Behavior in High Stress Situations in Aerospace Operations* (pp. 22-1 to 22-13). Neuilly Sur Seine, France: Advisory Group for Aerospace Research & Development. (AD-A212884)

This paper describes two studies conducted at the Fleet Fighter Air Combat Maneuvering (ACM) Readiness Program, Naval Air Station Oceana, Virginia. The purpose of the studies was to evaluate the prediction of ACM performance by using perceptual motor and cognitive multitask tests (Study I), and to assess the correlation of Tactical Aircrew Combat Training System (TACTS) performance measures and overall ACM grades (OAG) assigned by VF-43 (adversary squadron) personnel (Study II). Study I determined that OAG were significantly and positively related to offensive maneuvering, situational awareness (SA), and mutual support measures. In addition, dichotic listening test measures, derived under multitask conditions, could reliably predict ACM performance (n=18 F-4 pilots). Study II found that Fleet Fighter OAG can be predicted by an objective kill difference composite score, and subjective measures of situational awareness, mutual support and energy management (Subjects: 125 F-14 pilots).

KEYWORDS: air combat maneuvering (ACM), air-to-air mission, attention, aviation (military), cognitive processes, individual differences, measurement, performance-based measures, subjective measures, training

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80. Haines, R.F., and Flatau, C. (1992). *Night flying.* Blue Ridge Summit, PA: TAB Books.

This book is intended to aid pilots with night flying skills. SA is suggested as one important component of safe flying. SA is defined as (p. 43), "one's ability to remain aware of everything that is happening at the same time and to integrate that sense of awareness into what one is doing at the moment." SA is seen by the authors to be the result of both genetic and experiential influences. In addition, the authors suggest that some general exercises might increase an individual's SA capabilities. Five categories of exercises are suggested: (1) vision and attention scanning exercise, (2) listening exercise, (3) muscular exercise, (4) cognitive exercise, and (5) integration. However, no data is presented to support the effectiveness of these exercises.

KEYWORDS: attention, aviation (civilian), cognitive processes, definition, training

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81. Halski, D.J., Landy, R.J., and Kocher, J.A. (1991, April). Integrated control and avionics for air superiority: A knowledge-based decision-aiding system. In AGARD-CP-474, *Knowledge-Based System Applications for Guidance and Control* (pp. 53-1 - 53-11). Neuilly Sur Seine, France: Advisory Group for Aerospace Research & Development. (AD-A235715)

The purpose of the Integrated Control and Avionics for Air Superiority (ICAAS) program, sponsored by the Wright Research and Development Center, is to develop a real-time, knowledge-based decision-aiding system for air combat. ICAAS-developed critical technologies will focus on improving tactical fighter kill/survive capabilities when outnumbered during air combat. Situation awareness information and recommended actions will aid the pilot in selecting attack/defend options. The majority of the paper presents in-depth descriptions of the key ICAAS system functions (and improved capabilities): Attack Management (Situation Awareness), Tactics (Situation Assessment), Attack Guidance (Positional Advantage), Defensive Assets Manager (Threat Evasion), and Performance Monitor (Performance Advantage).

KEYWORDS: air-to-air mission, aviation (military), avionics, decision aiding, decision making, pilot aiding

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82. Hamilton, W.L. (1987). *Situation awareness metrics program* (SAE Technical Paper Series No. 871767). Warrendale, PA: Society of Automotive Engineers.

The author describes a four-part program to develop SA metrics to support the design of fighter cockpits. The importance of SA is emphasized (p. 1), "Situation awareness has historically been regarded by fighter pilots as a dominant factor in air combat." The author cites a definition with is said to be accepted by the Air Force (p. 1): "Situation awareness is knowledge of current and near-term disposition of both friendly and enemy forces within a volume of space." The author suggests that the definition is somewhat weak because it does not offer any real guidance to designers. The author proposes that SA must be understood within the context of the flow of necessary information to the pilot. The information must be filtered for relevance and displayed effectively to avoid overloading the pilot. The program that is proposed is described as having four phases: identify information requirements, develop candidate measures, establish methodology for analyzing the information filtering process, and analyze pilot information management of high rates of information flow. The candidate measures of SA are not described in detail but appear to emphasize performance-based "measures of merit." The SA measurement would also be complemented by the use of a workload assessment battery.

KEYWORDS: aviation (military), avionics, definition, display design, measurement, performance-based measures, workload

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83. Hansman, R.J., Hahn, E., and Midkiff, A. (1991). Impact of data link on flight crew situational awareness. In *Proceedings of the Sixth International Symposium on Aviation Psychology* (Volume 1, p. 551). Columbus: The Ohio State University.

This paper announces the concern for the potential loss of situational awareness as a result of incorporating data-linked air traffic control commands into the cockpit of commercial airliners. The concern is that the change will remove the pilot's access to "party-line information" that is currently available from listening to the air traffic controller's communications with other aircraft. A survey of current commercial airline pilots indicated that the pilots consider such party line information to be important. Also, preliminary studies suggest the pilots are more likely to accept "bad" clearances when using the data-link system than when using the traditional radio-based clearance system.

KEYWORDS: air traffic control, avionics, aviation (civilian), data link, measurement, performance-based measures, pilot aiding, questionnaire/survey data, subjective measures

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84. Hanson, R.F. (1988). Situation awareness and the PVI link. In *Proceedings of the AIAA/IEEE 8th Digital Avionics Systems Conference* (pp. 193-195). Washington, DC: American Institute of Aeronautics and Astronautics.

The author contends that SA is vital for mission success in a tactical fighter and that "Good Situation Awareness and good Pilot-Vehicle Interface (PVI) are rapidly becoming synonymous" (p. 193). The author suggests a research program for developing a methodology that would allow the SA needs of a pilot to be specified and then tested by appropriate performance-based measures of merit. The author suggests that this approach is essential to making SA a viable consideration in the design of the PVI. At the time of the writing the research was in the planning stages, so no results are presented.

KEYWORDS: air-to-air mission, aviation (military), display design, measurement, performance-based measures

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85. Harbour, J.L., and Hill, S.G. (1990). Using HSYS in the analysis of human-system interactions: Examples from the off-shore petroleum industry. In *Proceedings of the Human Factors Society 34th Annual Meeting* (Volume 2, pp. 1190-1194). Santa Monica, CA: Human Factors Society.

This article describes using a computational human information processing model to analyze 28 accidents that occurred in the offshore petroleum industry. The model is called the Humans-System (HSYS) model and it characterizes all human action in five sequential steps: input detection, input understanding, action selection, action planning, and action execution. The authors interpret some of the results in SA terms (p. 1191), "Situational awareness involves the real-time detection and understanding of various system and environmental inputs. In HSYS terminology, situational awareness includes both input detection and input understanding."

KEYWORDS: definition, modeling, retrospective measures, subjective measures

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86. Hardy, S.M. (1992, January). Air Force hits the intelligence fastball: Bringing real-time intelligence to the F-16 cockpit. *Journal of Electronic Defense, 15*(1), 29, 31, 69.

The article discusses Project Fastball. Project Fastball is an effort by the Air Warfare Center to bring real-time intelligence data to an F-16 cockpit. The system consists of three parts: (1) air and ground based sensors, (2) a data collection facility to analyze all of the data and broadcast it to the F-16, and (3) an on-board computer to generate the display on the HUD. The system had already passed tests in the simulator, in-flight tests at Eglin Air Force Base's test range, and in-flight tests at Nellis Air Force Base's Green Flag exercise. The system is described as a tool for improving SA.

KEYWORDS: aviation (military), avionics, data fusion, data link, flight test, pilot aiding

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87. Hardy, S.M. (1993, December). Raising the cockpit's IQ. *Journal of Electronic Defense, 16*(12), 51-56.

This article reviews several systems being developed under the umbrella term of real-time intelligence to the cockpit (RTIC). RTIC includes systems that not only down-link information into the cockpit, but up-link current information from one cockpit to distribute to others. The potential benefits of such systems are interpreted within an SA framework. For example the author concludes (p. 56), "Whether for self-defense, targeting, combat ID, or any one of a number of situational awareness aspects, real-time intelligence to the cockpit promises to bring pilots and weapons specialists a clearer picture of the environment than previously possible."

KEYWORDS: aviation (military), avionics, data link, flight test, pilot aiding, target identification

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88. Hart, S.G. (1989). Overview of NASA rotorcraft human factors research. In *American Helicopter Society 45th Annual Forum Proceedings* (pp. 441-453). Alexandria, VA: American Helicopter Society.

This article is a high-level review of numerous research programs that were being conducted by the Rotorcraft Human Factors Research Branch at NASA - Ames Research Center. Situational Awareness is identified as one of four major program elements for the branch. This program element is described as investigating near-term and long-term enhancements for the helicopter cockpit to improve pilot SA. Among the technologies discussed are: design of visual display systems, helmet-mounted displays (HMDs), 3-D audio, and map displays.

KEYWORDS: 3-D audio displays, display design, helicopter, helmet-mounted displays (HMDs), pilot aiding

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89. Hart, S.G., and Chappel, S.L. (1983). Influence of pilot workload and traffic information on pilot's situation awareness. In *Nineteenth Annual Conference on Manual Control* (pp. 4-26). Cambridge: Massachusetts Institute of Technology.

This paper reports the results of a study of the effects of a cockpit display of traffic information (CDTI) on SA and workload. The operation of multiple aircraft within a terminal control airspace was simulated. On half of the trials all aircraft were CDTI-equipped, on the other half only some of the aircraft were CDTI-equipped. Workload was also manipulated to produce low and high workload conditions. Workload was measured by self-rating device involving periodically pressing a button to indicate the current load. SA was measured by a "stop-action" procedure. This was a memory probe procedure that involved the abrupt stopping of a simulation with a blanking of the displays. Subjects were asked to fill out a form describing all of the traffic that existed at the time of the stoppage. Results indicated that the availability of CDTI increased reported workload, but did not improve the completeness or accuracy of the reported traffic information. Despite the increase in workload the pilots favored the implementation of CDTI. The scenarios that inflicted higher workload also tended to depress SA scores. Regardless of the availability of CDTI or the level of workload, the overall amount of information reported during the stop-action SA assessment was very little. This led to the suggestion by the authors that in future research (p. 25), "Remembered information should be but one element in the analysis. Information usage and strategies selected during the simulation should be studied as well, to obtain a complete analysis of the information extracted from a traffic display as a function of the tasks a pilot is performing."

KEYWORDS: air traffic control, aviation (civilian), display design, measurement, memory probe measures, performance-based measures, pilot aiding, workload

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90. Hartman, B.O., and Secrist, G.E. (1991). Situational awareness is more than exceptional vision. *Aviation, Space, and Environmental Medicine, 62,* 1084-1089.

The authors emphasize that situation awareness derives from cognitive processes more than exceptional sensory capabilities. They also suggest that situation awareness enhancement must include more than simply redesign of avionics and displays. As they put it (p. 1084): "We have chosen a different approach: to treat situational awareness as a skill generically exercised by all pilots in all aircraft at all stages of their cockpit careers and to select and to train for situation awareness." As a conceptual background for their approach, the authors review three theoretical domains in terms of their applicability to situation awareness in pilots: (1) Automatic processes are seen as a way to circumvent working memory capacity limitations. (2) Processing near-threshold information allows information outside the limits of conscious awareness to influence performance. (3) Skilled memory organizes the long-term store of information for adaptive real-time use. The authors suggest that training in these domains could increase pilot situation awareness. They have started a research program to examine the utility of training to increase near-threshold information processing.

KEYWORDS: cognitive processes, review paper, training

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91. Harwood, K., Barnett, B., and Wickens, C. (1988, April). Situational awareness: A conceptual and methodological framework. In *Proceedings of the Psychology in the Department of Defense Eleventh Symposium* (Tech. Report No. USAFA-TR-88-1, pp. 316-320). Colorado Springs, CO: US Air Force Academy. (AD-A198723)

Although no concise, original definition of situation awareness is offered, the authors provide considerable discussion of relevant definitional issues. This discussion is presented within the framework of situation awareness being information about the Where, What, Who, and When of a situation. The temporal component is emphasized in the discussion. In discussing relevant methodologies for investigating situational awareness the authors discuss two main issues: (1) Capturing the mental model used to perform a task, and (2) Embedding tasks within dynamic scenarios.

KEYWORDS: cognitive processes, definition, measurement, mental models

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92. Henderson, B.W. (1989, June 19). Kaiser improves helmet-mounted display to boost pilot's kill capability. *Aviation Week & Space Technology, 130*(25), 119, 121.

The article discusses the Agile Eye Plus helmet-mounted display system. Agile Eye Plus is a second generation system that allows a greater field-of-view, displays more types of information, and has some additional convenience features than the first generation system (Agile Eye). According to a representative of Kaiser the Agile Eye Plus system "increases the pilot's situational awareness" along with other capabilities. Simulator and in-flight tests have demonstrated dramatic increases in the kill ratio for pilots using the Agile Eye Plus. In some cases, the availability of the system more than offset experience differences among participating pilots. Reportedly, all pilots that have used the system were positive about its performance. The operational capabilities of the current system are discussed, and potential future developments (including the integration of data linked information onto the display) are suggested.

KEYWORDS: aviation (military), combat simulation, data fusion, data link, display design, flight test, helmet-mounted displays (HMDs), measurement, performance-based measures, pilot aiding, subjective measures

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93. Henderson, B.W. (1991, January 7). Aircraft-style avionics add punch to U.S. Army's next-generation tank. *Aviation Week & Space Technology, 134*(1), 45, 47-48.

The article discusses proposed "vetronics" (a contraction of "vehicle electronics") to be included in the M1A2 Abrams main battle tank. Among other things, the vetronics include an integrated command and control network, inertial navigation and fire control systems, and digital displays. This package will make the tank's control area very similar to current fighter aircraft designs and is expected to double defensive battle efficiency and increase offensive capability by 50%. Gordon England, vice president of engineering and research at General Dynamics Land Systems Division, is quoted as saying (p. 47), "Using the laser range finder, targets can be precisely located, and knowing where you are, you can communicate the position of targets to other tanks in the force. Situational awareness will be much better."

KEYWORDS: avionics, battlefield SA, data link

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94. Henderson, B.W. (1992, March 23). NASA Ames pushes automation toward human-centered design. *Aviation Week & Space Technology, 136*(12), 69-70.

The article describes NASA-Ames' research with "human-centered automation." The goal is to implement automation while helping the pilot maintain SA. The usual approach to implementing automation is described as "management by exception." In a management-by-exception scheme the automation proceeds with actions unless the human crew acts to stop it. The human crew operates as monitors of the automation's actions. This passive monitoring is considered to be incompatible with maintaining good SA. The alternative "human-centered" approach to implementing automation would be to use "management by consent." In a management-by-consent scheme, pilot action is required before even automatic maneuvers can be executed.

KEYWORDS: aviation (civilian), avionics, pilot aiding

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95. Henderson, B.W. (1992, November 23). Automation system gains acceptance. *Aviation Week & Space Technology, 137*(21), 97-98.

The Center/Tracon Automation System (CTAS) is a collaborative FAA/NASA software project to provide air traffic controllers with an automated decision aid to increase the flow of aircraft in and around airports. It consists of three parts: (1) Traffic Management Advisor -to help plan the most efficient landing order and assign landing times, (2) Final Approach and Spacing Tool - to assist in guiding aircraft to the appropriate runway, and (3) Descent Advisor - to calculate cruise and descent clearances. The Traffic Management Advisor was tested in Denver and managers there reported that it helped their situational awareness. The primary benefits of the system are seen as a reduction in the air traffic controllers' workload combined with an increase in SA.

KEYWORDS: air traffic control, decision aiding, decision making, workload

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96. Henderson, E.D. (1988). *Air traffic controller awareness and resource training* (SAE Technical Paper Series No. 881518). Warrendale, PA: Society of Automotive Engineers.

Human error is cited as the cause of a very large proportion (over 90%) of the operational errors observed in the air traffic control system. A major contributor to these errors may be a lack of team skills and communication among air traffic controllers. The article describes the Controller Awareness and Resource Training (CART) program. CART is an attempt to provide training analogous to airline Cockpit Resource Management (CRM) training to air traffic controllers. Of the fourteen sessions or lessons that constitute the CART training, one lesson is devoted to SA. More specifically, the lesson discusses (p. 3) the "ability to recognize the elements of situational awareness when it may have been lost, and how to regain or maintain it." The goal of the CART program is to improve the safety and efficiency of the air traffic system.

KEYWORDS: air traffic control, cockpit resource management (CRM), team SA, training

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97. Hitchcock, L. (1994). Yours, mine, and ours: Some observations on the metaphysics of situational awareness. In R.D. Gilson, D.J. Garland, and J.M. Koonce (Eds.), *Situational awareness in complex systems: Proceedings of a CAHFA Conference* (pp. 3-16). Daytona Beach, FL: Embry-Riddle Aeronautical University Press.

The author attempts to address the potential effects of an individual observer on SA, especially the effect on communicating SA from one person to another person (such as in air traffic control). To attack this issue Hitchcock uses the "pseudo" pyramid representation of SA developed by Harwood, Barnett, and Wickens (1988) to represent the where, what, when, and who components of SA. Hitchcock contends that each individuals unique approach to SA can be represented by a "Cognitive Centroid" that is located somewhere within the conceptual space of the "pseudo" pyramid. The quality of communicated SA will be influenced by the distance between the locations of the cognitive centroids of the individuals involved.

KEYWORDS: cognitive processes, individual differences, team SA

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98. Hoover, G.W. (1992, June 15). Stop saturating pilots with alphanumeric hieroglyphics. *Aviation Week & Space Technology, 136*(24), 98-99.

The article argues that there is an excessive reliance on presenting pilots obscure alphanumeric information. The author argues for pictorial displays that would simulate the cues of the natural world. As part of the justification for this, the author states (p. 99), "Research has proved that good pictorial visual information is a powerful counter to vertigo and will rapidly restore a pilot's situational awareness. It should. He is using the same cues in flight that he has used every day since he first opened his eyes."

KEYWORDS: aviation (civilian) display design, pilot aiding

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99. Hopkin, V.D. (1994). Situational awareness in air traffic control. In R.D. Gilson, D.J. Garland, and J.M. Koonce (Eds.), *Situational awareness in complex systems: Proceedings of a CAHFA Conference* (pp. 171-178). Daytona Beach, FL: Embry-Riddle Aeronautical University Press.

The author reviews some of the conceptual issues involved in applying the SA concept to air traffic control. In discussing SA in air traffic control the author connects it to the concept of the controller's "picture" (p. 174): "In air traffic control, situational awareness seems to correspond quite well with the concept of the controller's picture. This picture is sometimes construed as an example of a mental model but although the picture includes the controller's mental model it is not confined to it, being a more dynamic entity than most mental models in that it incorporates changing states and their consequences." The potential effects of individual differences, training, and automation are also discussed. In particular, many of the current plans to automate the air traffic controller's job are seen as possibly degrading the SA achievable by future air traffic controllers.

KEYWORDS: air traffic control, cognitive processes, individual differences, mental models, training

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100. Hoshstrasser, B.D., and Small, R.L. (1994). The impact of associate systems technology on an air traffic controller's situational awareness. In R.D. Gilson, D.J. Garland, and J.M. Koonce (Eds.), *Situational awareness in complex systems: Proceedings of a CAHFA Conference* (pp. 227-236). Daytona Beach, FL: Embry-Riddle Aeronautical University Press.

The authors discuss the issues associated with applying artificially-intelligent associate systems to aiding air traffic controllers. They identify numerous potential payoffs and pitfalls, and make suggestions for future applications.

KEYWORDS: air traffic control, design guidelines

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101. Houck, R., Kelly, B.D., and Wiedemann, J. (1986). *An integrated display for vertical situation awareness in commercial transport aircraft* (SAE Paper No. 861770). Warrendale, PA: Society of Automotive Engineers.

One of the most frequently reported safety violations in commercial aviation is deviation from assigned altitude. The authors suggest that this is because there is no adequate display of the aircraft's vertical situation. They argue that a well-designed vertical situation display (VSD) would provide a significant benefit to the commercial aircraft cockpit. As they put it (p. 61): "With the advent of new CRT technology, many innovative pictorial display presentations are possible to depict the airplane's position in space. These pictorial displays incorporate features that take advantage of the pilot's decision-making and discriminatory capabilities, thereby resulting in greater situational awareness, better planning, and reduced workload." Alternative approaches to the design of such a display are described and contrasted. However, at the time of the writing, no empirical evaluation of any of the display formats had been conducted.

KEYWORDS: aviation (civilian), display design, pilot aiding, pilot error, workload

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102. Houck, R.D., Rogers, W.H., and Braune, R.J. (1987). *Advanced technology cockpit design and the management of human error* (SAE Paper No. 872525). Warrendale, PA: Society of Automotive Engineers.

In addressing the issue of pilot error in commercial aviation the authors suggest that advanced technology in the cockpit must be carefully employed. As one aspect of this discussion, they emphasize that the use of advanced technology (such as automation or pictorial displays) should be guided by the need to increase pilot situational awareness. SA is thus seen as beneficial to the reduction of pilot error. The authors also suggest that new control laws in the cockpit could reduce manual control workload, which could allow more time for maintaining better SA.

KEYWORDS: aviation (civilian), avionics, display design, pilot aiding, pilot error, workload

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103. Howell, W.C. (1993). Engineering psychology in a changing world. *Annual Review of Psychology, 44*, 231-263.

As part of a review of the larger topic of engineering psychology, the author devotes a few pages to discussing the status of the SA concept and SA research. Addressing the definitional issue, the author states (p. 241), "While definitions vary, the essential idea is that an operator must keep track of a lot of information from a variety of sources over time and organize or interpret this information to behave appropriately." Numerous studies are discussed, but few real conclusions could be reached from the existing data. The main points made are: (1) the conceptual underpinnings must be identified and explored, (2) the pressure to produce a useful measure and immediately apply it to selection, training, or design is growing and could be dangerous, and (3) it would be a mistake to allow any existing measure of SA to prematurely become the "accepted operationalization of SA."

KEYWORDS: cognitive processes, definition, implicit measures, measurement, memory probe measures, mental models, review paper, SAGAT, SART, subjective measures, workload

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104. Hubbard, D.C., Rockway, M.R., and Waag, W.L. (1989). Aircrew performance assessment. In R.S. Jensen (Ed.), *Aviation psychology* (pp. 342-377). Aldershot, United Kingdom: Gower.

The authors describe the need for good performance measures of pilots or aircrews. These measures would be useful for aircrew selection, training, and research and development. Many approaches are described and discussed. Within this context the authors express reservations about the concept of SA (p. 375), "Within the tactical domain, the concept of situational awareness is used quite frequently to describe skills in maintaining an awareness of the tactical situation. For multicrew aircraft, the concept of 'captaincy' is often used to describe skills unique to assuming the role of aircraft commander. Unfortunately, there are no universally accepted definitions of these concepts. It would not be uncommon to have five pilots give five different definitions for such concepts. It is apparent that attempts to develop measures of such ill-defined concepts are, at best, extremely difficult."

KEYWORDS: aviation (military), definition, measurement, performance-based measures

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105. Hughes, D. (1992, March 9). JTIDS links air, land, sea forces in first tri-service cooperative tests. *Aviation Week & Space Technology, 136*(10), 56-57.

The Joint Tactical Information Distribution System (JTIDS) was successfully tested as a tool to integrate tactical information among units from the Air Force, Army, and Navy. JTIDS data links were successful in putting six military aircraft, a Navy ship, two ship simulators, and two Army ground terminals together in a network. Within this network, sensor data could be exchanged in real-time. This permitted new air-to-air tactics that would not be possible without the data link. Summing up the potential value of the system, the author states (p. 57), "Increased situational awareness will make it possible to respond faster to a threat with a coordinated offensive or defensive move."

KEYWORDS: air-to-air mission, aviation (military), avionics, battlefield SA, data link, flight test, naval SA, pilot aiding

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106. Hughes, D. (1992, October 12). Cameras could give pilots exterior views of aircraft. *Aviation Week & Space Technology, 137*(15), 32-33.

The addition of external cameras to British Airways Boeing 747s is discussed as an accident prevention and problem diagnosis tool. The cameras would allow the flight crew to visually inspect the aircraft's engines from the cockpit, even in flight. Used in this way, the cameras are described as "situational awareness aids" (p. 32).

KEYWORDS: aviation (civilian), pilot aiding

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107. Hughes, D. (1992, November 23). Boeing, United pursue major cockpit advance. *Aviation Week & Space Technology, 137*(21), 89-91.

Boeing and United Airlines are working together to develop the Enhanced Situation Awareness System (ESAS) for commercial aircraft. The system will fuse data from a variety of sensor systems (such as forward looking infrared cameras, millimeter-wave and x-band radar, video cameras, etc.) that could improve terrain and obstacle avoidance, landings, and flight through hazardous weather conditions. The goal is to "place the pilot in a VFR-like situation at all times" (p. 89). It is expected that this system would increase safety, decrease delays due to weather, and allow aircraft more access to airports with limited navigation and landing aids. The greatest technical challenge for the system designers is expected to be the human-machine interface.

KEYWORDS: aviation (civilian), avionics, data fusion, display design, pilot aiding

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108. Hughes, D. (1993, July 26). USAF, Navy pursue NVGs for fighters, bombers. *Aviation Week & Space Technology, 139*(4), 44-45.

The Air Force and Navy are developing new night-vision goggle systems designed specifically for fixed-wing aircraft (fighters, bombers, transport, and tankers). The logic for this program was described as follows (p. 44), "The systems can be used for low-level navigation at night, night refueling, landing at blacked-out airfields and even identification and tracking of an intruder aircraft by an interceptor. The systems are intended to enhance situational awareness rather than to aid the pilot in air-to-air or air-to-ground target acquisition."

KEYWORDS: aviation (military), helmet-mounted displays (HMDs), pilot aiding, target identification

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109. Hughes, D., and Lenorovitz, J.M. (1991, June 24). F-117A's performance boosts wide range of improvements. *Aviation Week & Space Technology, 134*(25), 20-23.

The article describes planned upgrades to the Air Force's F-117A Stealth fighter. Among the changes proposed for the F-117A are additions to the cockpit (p. 21), "The F-117's offensive capability also is being improved through the addition of Honeywell color multi-function displays with the capability to integrate a digital moving map by Harris Corp. to give pilots greater situational awareness." It was believed that this program marked the first operational use of military-qualified digital map technology in a fighter-category aircraft. It was also hoped that the cockpit changes would reduce the potential for accidents caused by pilot disorientation.

KEYWORDS: aviation (military), data fusion, display design, pilot aiding

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110. Hughes, E.R., Hassoun, J.A., Ward, G.F., and Rueb, J.D. (1990, July). *An assessment of selected workload and situation awareness metrics in a part-mission simulation* (Tech. Report No. ASD-TR-90-5009). Wright-Patterson Air Force Base, OH: Aeronautical Systems Division.

This experiment investigated the use of SAGAT and SA-SWORD as situation awareness metrics in air-to-air part mission simulator. Situation awareness was manipulated by sensor and display type. Half of the trials used a typical forward-looking radar displayed on a current fire-control radar (FCR) display. The other half of the trials simulated the use of data-linked information from off-board sensors along with radar information displayed on a Horizontal Situation Format (HSF) display. SAGAT was insensitive to the display configuration manipulation. However, there was concern that the small number of trials, limited training time for subjects, and experimental design might not have been compatible with a SAGAT analysis. SA-SWORD was sensitive to the display configuration manipulation. The pilots felt that the HSF display significantly improved situation awareness. The study also included analysis of performance measures and subjective and physiological workload measures.

KEYWORDS: aviation (military), combat simulation, data fusion, data link, display design, measurement, memory probe measures, performance-based measures, pilot aiding, SAGAT, SA-SWORD, subjective measures, workload

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111. Johnston, J.C., Horlitz, K.L., and Edmiston, R.W. (1993). Improving situation awareness displays for air traffic controllers. In *Proceedings of the Seventh International Symposium on Aviation Psychology* (Volume 1, pp. 328-334). Columbus: The Ohio State University.

This paper reviews the results of four laboratory visual search experiments that compared different display approaches for air traffic controller's Situation Awareness Displays (SADs). The goal was to use display formatting that emphasized the natural perception of the important information rather than the cognitive calculation of a display's meaning. As a test case, the authors examined different approaches for representing the altitudes of aircraft on the controller's SAD display. The dependent measure was generally the response time for correct responses. The results found that coding the aircrafts' altitudes by color was most effective, using achromatic coding schemes (such as gray-scale or dot-striping) showed some promise, and coding based on size or shape were generally ineffective. In addition to these specific findings, the authors argue that the results support small laboratory part-task evaluations as a viable way to "sort out promising from unpromising display schemes" (p. 332).

KEYWORDS: air traffic control, display design, measurement, performance-based measures

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112. Judge, C.L., and Bushman, J.B. (Panel Co-Chairs) (1992). Situation awareness: Modeling, measurement, and impacts. In *Proceedings of the Human Factors Society 36th Annual Meeting* (Volume 1, pp. 40-42). Santa Monica, CA: Human Factors Society.

This set of abstracts summarizes a panel session. The Introduction presents a definition of SA that has been accepted by the Air Force operational community (p. 40), "A pilot's continuous perception of self and aircraft in relation to the dynamic environment of flight, threats, and mission and the ability to forecast, then execute tasks based on that perception." The goal of the panel was to present current research in the role of SA in aviation and speculate on future directions. Five abstracts follow the introduction: Michael Vidulich (*Measuring Situation Awareness*), Michael Houck (*Situation Awareness in Beyond-Visual-Range Air Combat*), Frederick M. Seim and David Perry (*A Test Battery to Predict Individual Differences in Situational Awareness*), J. Raymond Comstock (*Human/Automation, Integration, and Situation Awareness*), and Cynthia Dominguez (*Visual Identification in Near-Threshold Processing*).

KEYWORDS: aviation (civilian), aviation (military), cognitive processes, definition, individual differences, measurement, pilot aiding, training

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113. Kaempf, G.L., Wolf, S., and Miller, T.E. (1993). Decision making in the AEGIS Combat Information Center. In *Proceedings of the Human Factors and Ergonomics Society 37th Annual Meeting* (Volume 2, pp. 1107-1111). Santa Monica, CA: Human Factors and Ergonomics Society.

The paper reviews an evaluation of the decision processes of anti-air warfare (AAW) officers in the Combat Information Center (CIC) of an AEGIS cruiser. AEGIS cruisers combine advanced radar systems with anti- aircraft missiles to provide air defense for Navy task forces. Interview data was collected from 28 experienced AAW officers discussing 14 separate operational incidents. The procedures followed in setting up the interviews, extracting the knowledge, and creating the recommendations were inspired by Klein's Naturalistic Decision Making (NDM) research. Data regarding 183 operational decisions were collected. The selection of a course of action in these incidents was typically (i.e., 95% of the time) determined by the formation of a situation assessment by the operator. Only in 5% of the cases were multiple options generated and compared. Given that the situation assessment discussed by NDM researchers can be considered one form of situation awareness, this result suggests that SA is a vital component of real-world performance. Approaches for designing decision aids are also discussed.

KEYWORDS: cognitive processes, decision aiding, decision making, naval SA, questionnaire/survey data, retrospective measures, subjective measures

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114. Kass, S.J., Herschler, D.A., and Companion, M.A. (1990). Are they shooting at me?: An approach to training situational awareness. In *Proceedings of the Human Factors Society 34th Annual Meeting* (Volume 2, pp. 1352-1356). Santa Monica, CA: Human Factors Society.

This paper describes a study in which the authors investigated a training strategy to improve situational awareness. Twenty civilians (University of Central Florida volunteers), divided into two groups, were trained in location identification on a tank muzzle flash task. One group received only flashes in training; members of the second group were presented with flashes plus additional stimuli as clutter. During testing (random flashes, with clutter), subjects in the first group scored significantly better. These results, according to the authors, suggest that "pattern recognition skills are best developed in a minimum-stimulus condition." The authors also incorporate brief discussions of Rasmussen's progressive levels of cognitive processing (knowledge-based, rule-based, and skill-based behaviors), Teichner's task theory, signal detection theory, and state-dependent learning theory into the explanation of their study.

KEYWORDS: battlefield SA, cognitive processes, measurement, performance-based measures, training

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115. Kass, S.J., Herschler, D.A., and Companion, M.A. (1991). Training situational awareness through pattern recognition in a battlefield environment. *Military Psychology, 3,* 105-112.

This paper is a revised and slightly expanded version of the Kass, Herschler, and Companion (1990) paper and is reviewed under that citation.

KEYWORDS: battlefield SA, cognitive processes, measurement, performance-based measures, training

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116. Kelly, M.J. (1988). Performance measurement during simulated air-to-air combat. *Human Factors, 30*, 495-506.

This article reports on different approaches for automating the air combat maneuvering (ACM) performance assessment of pilots flying complex air combat missions in high fidelity simulators. Problems with maintaining SA are considered part of the justification for needing such systems (p. 496): "An ACM performance measurement system (ACMPMS) can provide information storage and processing that are complimentary to the cognitive abilities and limitations of the human pilot and instructor by augmenting their memories and situational awareness, which may become overloaded during the mission." Describing what is meant by the term "situation awareness," the author states (p. 499): "The pilot needs to be keenly aware of the relative positions of the terrain and all friendly and adversary forces as well as able to project such positions and actions into the future. Situation awareness is probably the sum of numerous perceptual and cognitive skills." The author concludes that an algorithm must combine information about the superiority/inferiority of the pilot's aircraft relative to the adversary, along with measures of control use, energy management, SA, and team support to be effective.

KEYWORDS: air combat maneuvering (ACM), air-to-air mission, aviation (military), combat simulation, definition, measurement, performance-based measures, subjective measures, team SA, training

117. Kibbe, M.P. (1988). Information transfer from intelligent EW displays. In *Proceedings of the Human Factors Society 32nd Annual Meeting* (Volume 1, pp. 107-110). Santa Monica, CA: Human Factors Society.

The results of two experiments to examine the effect of automation in the combat aircraft cockpit on situation awareness were reported, and the design of a third experiment was outlined. The motivation for the research was concern that automation might reduce situation awareness. The author defined SA as, "The particular kind of SA investigated here is tactical situational awareness (TSA) which includes knowledge of the status of one's own aircraft, other aircraft, and ground threats and targets" (p. 107). The effects of automation on SA were studied by having the subjects perform a threat recognition task on a laboratory simulation of a Radar Warning Receiver (RWR). The threat recognition task required manual inputs in Experiment 1, but was automated in Experiment 2 and only required monitoring. The threat recognition task was performed as either a single task or as a dual task combined with a tracking task. Although not identified as such by the author, the performance on the tracking task was treated as a workload metric. Tracking performance was degraded by the addition of the threat recognition task, even in the automated condition. Tracking performance on the automated dual task trials was approximately half-way in-between single task tracking and the manual threat identification dual task condition tracking performance. SA was measured by a retrospective questionnaire filled out after the trial. The subjects were asked to reconstruct the timeline of threat appearances during the trial. No effect of automation on the accuracy of these reconstructions was detected.

KEYWORDS: aviation (military), avionics, definition, measurement, performance-based measures, pilot aiding, questionnaire/survey data, retrospective measures, subjective measures, target identification, workload

118. King, P.A. (1987). Big picture: A solution to the problem of situation awareness. In *Proceedings of the IEEE 1987 National Aerospace and Electronics Conference - NAECON 1987* (Volume 1, pp. 261-265). New York: Institute of Electrical and Electronics Engineers.

The author contends that one of the major difficulties facing the pilot of contemporary fighter aircraft is the proliferation of displays. As aircraft sensor capabilities have increased new displays have been added in a piece-meal fashion to display the information of each sensor system independently. The pilot must then fuse the information from these different displays. The time available is often insufficient for the information to be properly understood by the pilot. This paper describes a display concept developed by McAir and the Air Force Wright Laboratory to address this problem. The display concept is called "Big Picture," and involves integrating all of the information together on a large (about 300 square inch) display area. A variety of data (e.g., ownship position, location and identity of other aircraft, threat and target locations, route-of-flight, etc.) is overlaid on a background display (either a digital map or a perspective view of forward terrain). A simulation facility to test this concept is described and some technical challenges for implementing the system in a real cockpit are discussed. The author states (p. 265), "Preliminary data indicate that the Big Picture concept improves pilot situation awareness and is the best way to provide the data collected by multiple sensors."

KEYWORDS: aviation (military), big picture displays, display design, pilot aiding

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119. Kinsley, S.A., Warner, N.W., and Gleisner, D.P. (1985, December). *A comparison of two pitch ladder formats and an ADI ball for recovery from unusual attitudes* (Tech. Report No. NADC-86012-60). Warminster, PA: Naval Air Development Center. (AD-A181253)

This study was initiated in part due to suspicion that the F/A-18 heads-up display (HUD) symbology provides inadequate attitude awareness. Pilots rated this HUD "marginally acceptable" when recovery from unusual attitudes was involved. Two experiments were performed. One used static depictions of attitude indicator displays showing unusual attitudes; measures were decision time (time to initiate a control response) and error rate in control response. The current HUD pitch ladder was compared with an improved modification of the HUD pitch ladder symbology and with an ADI ball. Decision time for the ADI ball was significantly faster than for the two pitch ladders. The second experiment evaluated the current HUD display and the ADI ball formats in a dynamic simulation. Decision time and recovery time were measured. Decision time was significantly faster against a clear blue sky than against a night sky with stars. These two backgrounds were evaluated because of the strong conviction by the authors that "the lack of a real, visible horizon is one of the primary causes of the loss of SA" (p. 4). Recovery time was significantly faster for the ADI ball than for the HUD pitch ladder. The authors recommend placement of an ADI ball in a prominent position in the F/A-18 pilot's visual field. They also discuss other options which would provide similar information in the pilot's primary viewing area.

KEYWORDS: attitude displays, aviation (military), display design, measurement, performance-based measures, pilot aiding, pilot error, subjective measures

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120. Klein, G.A. (1989a, May). Strategies of decision making. *Military Review, 69*(5), 56-64.

Klein uses this article to present his Recognitional Decision Making (RDM) theory to the operational Army officer community and to discuss its implications to their environment. Basically, he suggests that too much of the Army's guidance about the decision-making process assumes that analytical decision making involving the comparison of multiple options is the best or even the only way to make decisions. Klein argues that in the decision making of experts, such reliance on comparing options is not common and may not be desirable. The key issue in many of these settings is whether the situation assessment formed by the decision maker is well executed. In RDM theory, the situation assessment of an expert will directly lead to a workable solution path. Klein discusses how Army staff interactions and training can be designed to support and improve this approach to decision making.

KEYWORDS: battlefield SA, cognitive processes, decision aiding, decision making, expertise, team SA, training

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121. Klein, G.A. (1989b). Recognition-primed decisions. In W.B. Rouse (Ed.), *Advances in man-machine systems research* (Volume 5, pp. 47-92). Greenwich, CN: JAI Press.

This paper is an early theoretical treatment of the Recognition-Primed Decision (RPD) model. Reviewing the results of several evaluations of real-world decision making, Klein suggests that the traditional model of analytical decision making by the comparison of alternatives must be supplemented by the RPD model. The RPD model suggests that the decision maker forms a situation assessment of the current situation, and this situation assessment is directly linked with a potential solution. Unless mental simulation of attempts to use the indicated solution prove it to be unworkable, no other options are typically considered. Increasing expertise or time pressure will increase the likelihood that a RPD approach will be utilized.

KEYWORDS: cognitive processes, decision making, expertise, measurement, mental models, retrospective measures, subjective measures

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122. Klein, G.A. (1993, April). *Naturalistic decision making: Implications for design* (CSERIAC State of the Art Report 93-01). Wright-Patterson Air Force Base, OH: Crew System Ergonomics Information Analysis Center.

This report reviews the basic tenets of Klein's Naturalistic Decision Making (NDM) model. The emphasis is on the pragmatic issues of using NDM models to help guide the design and development of human-machine interfaces. Topics discussed include the decision strategies commonly used by operators that emphasize situation assessment, how cognitive task analysis can be used to define the decision requirements of operators, and the potential role of NDM in cognitive systems engineering to design interfaces that reflect normal cognitive processes.

KEYWORDS: cognitive processes, decision aiding, decision making, expertise, measurement, retrospective measures, subjective measures

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123. Klein, G.A., Calderwood, R., Clinton-Cirocco, A. (1986). Rapid decision making on the fire ground. In *Proceedings of the Human Factors Society 30th Annual Meeting* (Volume 1, pp. 576-580). Santa Monica, CA: Human Factors Society.

The decision making procedures used by skilled fire ground commanders (FGCs) was studied. Data on the process were collected using retrospective reports of the thought processes experienced during actual incidents. These data were collected in semi-structured interviews. The data were then analyzed by looking for "decision points" (defined as "a point in time when non-trivial alternative courses of action are available" (p. 576)) and keeping track of "situational awareness" (defined as "the information and cues that the FGC was considering at the time of each event" (p. 577)). A major finding of the study was that multiple alternative courses of action were rarely weighed against each other. Instead of comparing alternatives, the FGC's choices were most commonly based on their situational awareness of the current situation and generating an analogous situation from experience. This observation of the decision making process led the author to forming the "recognition-primed decision (RPD) model."

KEYWORDS: cognitive processes, decision making, definition, expertise, measurement, questionnaire/survey data, retrospective measures, subjective measures, verbal protocols

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124. Klein, G.A., Orasanu, J., Calderwood, R., and Zsambok, C.E. (Eds.) (1993). *Decision making in action: Models and methods*. Norwood, NJ: Ablex.

This book presents 23 chapters that review the development, methods, and applications of naturalistic decision making theories. Situation assessment is a key component of many of the models and theories presented.

KEYWORDS: cognitive processes, decision aiding, decision making, expertise

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125. Klinger, D.W., and Gomes, M.E. (1993). A cognitive systems engineering application for interface design. In *Proceedings of the Human Factors and Ergonomics Society 37th Annual Meeting* (Volume 1, pp. 16-20). Santa Monica, CA: Human Factors and Ergonomics Society.

This article describes using a Cognitive Task Analysis procedure to identify problems faced by AWACS Weapons Directors (WDs) and then to guide development of solutions to those problems. Five problem areas were identified for the current system: attention, memory, situational awareness, workload, and decision making. An alternative display concept was developed and tested in a high-fidelity simulation of the WD's task. Based on improvements in various measures of effectiveness of the WD's performance, the authors contend that SA was improved.

KEYWORDS: attention, aviation (military), cognitive processes, combat simulation, decision making, display design, measurement, performance-based measures, pilot aiding

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126. Kuchar, J.K., and Hansman, R.J. (1993). An exploratory study of plan-view terrain displays for air carrier operations. *The International Journal of Aviation Psychology, 3,* 39-54.

This research investigated the utility and possible designs for Terrain Situation Awareness Displays (TSA). TSA was described by the authors (p. 40) as involving, "the presentation of terrain information in a manner that allows the pilot to create a mental model of the topography surrounding the aircraft's planned trajectory." Two formats for presenting terrain information on the TSA were compared: (1) a spot-elevation display indicating local peak elevations, and (2) a smoothed-contour display of local terrain. The smoothed-contour display supported better hazard recognition performance. The pilots were also asked to rate the two displays on a five-point SA scale at the completion of the evaluation. There was a statistically significant difference in the ratings for the two displays. The smoothed contour display was rated as providing superior TSA.

KEYWORDS: aviation (civilian), cognitive processes, display design, measurement, mental models, performance-based measures, pilot aiding, subjective measures

127. Kuperman, G.G., and Wilson, D.L. (1988). The design of a tactical situation display. In *Proceedings of the Human Factors Society 32nd Annual Meeting* (Volume 1, pp. 111-115). Santa Monica, CA: Human Factors Society.

The paper reviews the development of a Tactical Situation Display (TSD) for a conceptual next-generation strategic bomber. Such a display was considered necessary in order to allow the crew to deal effectively with changing missions in real-time while having only incomplete information. Preliminary evaluation of some of the display concepts was discussed in Marshak, Kuperman, Ramsey, and Wilson (1987).

KEYWORDS: aviation (military), display design, pilot aiding

128. Lesser, R. (1993, June). Avionics 2000 -- "May I help you?" *Defense Electronics, 25*(7), 37-40.

The article discusses two research programs designed to evaluate the role artificial intelligence can play in improving pilot SA. The two programs are the Air Force Pilot's Associate (PA) program and the Army's Rotorcraft Pilot's Associate (RPA) program. In both cases, AI is being tested as a means to filter and integrate mission relevant information and present it to the pilot in the most effective manner. One goal of the program is to improve pilot SA. A preliminary test of the PA system with F-15 pilots generated "enthusiastic" support for the system. Some elements of PA are being implemented in the F-22 avionics package.

KEYWORDS: aviation (military), avionics, data fusion, helicopter, measurement, pilot aiding, subjective measures

129. Lippert, F.G., Shechter, J., and Burke, J. (1989). Pilot/surgeon inflight decision making: A study of the integration of aviation and operating room cognitive skills. In *Proceedings of the Fifth International Symposium on Aviation Psychology* (Volume 1, pp. 366-370). Columbus: The Ohio State University.

This paper discussed SA as one element that flying an aircraft and doing surgery might have in common. The similarities and differences between the two settings in terms of SA are discussed. The SA abilities of pilots that were also practicing physicians were assessed in a dynamic scenario of aviation events. The pilot/physicians were asked to give verbal summaries of their situation assessments at periodic points in the scenario. These reports were then compared to the true situation to provide one measure of SA. Another measure of SA was provided by observer pilot ratings. The authors report that the pilot/physicians were much less likely to investigate and solve SA discrepancies in the aircraft than they would in the operating room. Based on this, the authors conclude that there is little automatic transfer of the decision making skills of physicians to aviation.

KEYWORDS: aviation (civilian), cognitive processes, decision making, measurement, subjective measures, verbal protocols

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130. Lum, Z.A. (1993, September). The path to heightened awareness. *Journal of Electronic Defense, 16*(9), 43-44, 46, 48.

The author identifies SA as a term that "rings like a mantra through the halls of the Pentagon" (p. 43). To help pin down the concept, the author examines three examples of systems designed to improve combat SA; one system from each of the three military services. All three systems highlight the potential for new sensor, communication, and data processing technology to provide combatants with a much larger and more complete picture of the combat environment. The possibility that threat assessment and tactical option selection could be automated is also discussed. Finally it is noted that (p. 48), "In the end,... the trick will be not to supply enough information to the user, but to manage the gouts of data in a usable form."

KEYWORDS: aviation (military), avionics, battlefield SA, decision aiding, naval SA, pilot aiding, target identification

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131. Marshak, W.P., Kuperman, G., Ramsey, E.G., and Wilson, D. (1987). Situational awareness in map displays. In *Proceedings of the Human Factors Society 31st Annual Meeting* (Volume 1, pp. 533-535). Santa Monica, CA: Human Factors Society.

Situation awareness was assessed for two different map display formats: a track-up moving map display, and a north-up moving plane display. A situation awareness metric was developed. It consisted of summing the absolute percent error across a series of probe questions asked at random times while the subjects were monitoring a mission on one of the displays. Despite extremely noisy dat' the memory probe situation awareness metric was successful in discriminating between flight pa' of different levels of complexity and the two types of displays. Additionally, subjects were asked to ›ut a preference questionnaire following the experiment. The preference data dissociated from the ᵤrformance data. Whereas performance was better with the moving map display, the subjects preferred the moving plane display. The authors conclude that use of subjective evaluation is risky unless the subjective results are supported by appropriate performance data.

KEYWORDS: aviation (military), display design, measurement, memory probe measures, pilot aiding, questionnaire/survey data, retrospective measures, subjective measures

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132. Masters, R.M., McTaggart, T.E., and Green, G.L. (1986). *Air-to-air F-15/F-16 identification analysis methodology - Management summary* (Tech. Report No. ASD-TR-87-5004). Wright-Patterson Air Force Base, OH: Combat Identification System Program Office. (AD-B108209)

This report is an unclassified management summary of the objectives, methodology, analytical process and application of an NCTR (Non-Cooperative Target Recognition) Identification study. Situation Awareness is defined here as "the ability to envision the current and near-term disposition of both friendly and enemy forces." The study, conducted for the Air Force Combat Identification System Program Office, analyzed ID requirements for F-15s and F-16s in the 1990s. The specific focus was composite fire control/ID system performance parameters for a future integrated sensor suite.

KEYWORDS: air-to-air mission, aviation (military), avionics, data fusion, definition, target identification

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133. McKinley, R.L., Erikson, M.A., and D'Angelo, W.R. (1994). 3-Dimensional auditory displays: Development, applications, and performance. *Aviation, Space, and Environmental Medicine, 65*(5, Supplement), A31-A38.

This article reviews both laboratory and in-flight evaluation of a 3-D audio display system. The in-flight tests were conducted in a AV-8B "Harrier" aircraft. Summarizing the results of the in-flight test, the authors state (p. A31): "Flight test results demonstrated successful cued target acquisition, a subjective decrease in target acquisition times, a subjective improvement in speech intelligibility, a subjective increase in situational awareness, and a subjective decrease in pilot workload."

KEYWORDS: 3-D audio displays, aviation (military), display design, flight test, measurement, subjective measures, workload

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134. Melanson, D., Curry, R.E., Howell, J.D., and Connelly, M.E. (1973). The effects of communications and traffic situation displays on pilots awareness of traffic in the terminal area. In *Proceedings of the Ninth Annual Conference on Manual Control* (pp. 25-39). Cambridge: Massachusetts Institute of Technology.

The authors were asked to determine the "assurance" of pilots using a proposed Traffic Situation Display (TSD) with or without "shared" communications that allowed monitoring of communications of air traffic control with other aircraft. The authors equated "assurance" with awareness and defined awareness as having four components in their evaluation: (1) knowledge of own position, (2) knowledge of the positions of others, (3) ability to predict the future evolution of the traffic situation, and (4) ability to choose an appropriate escape route. Awareness was measured by a "stop-action quiz" that involved freezing and blanking the displays unexpectedly during a trial and asking the subjects to fill in a map with the relevant information. Mental workload was assessed by an auxiliary self-paced task to be performed along with the simulated flight control. Both the stop-action quiz and the workload measure were sensitive to some of the experimental manipulations.

KEYWORDS: air traffic control, aviation (civilian), definition, display design, measurement, memory probe measures, pilot aiding, workload

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135. Metalis, S.A. (1993). Assessment of pilot situational awareness: Measurement via simulation. In *Proceedings of the Human Factors and Ergonomics Society 37th Annual Meeting* (Volume 1, pp. 113-117). Santa Monica, CA: Human Factors and Ergonomics Society.

The primary objective of this paper is to present an approach for measuring SA in cockpit design evaluations. Concerned about the lack of a good definition of SA ("they tend to use one mentalistic term to define another" (p. 114)), the author suggests that efforts focus on agreeing about the operationalisms associated with influencing SA. According to the author (p. 113), "SA appears to involve the development and maintenance of a highly dynamic mental representation of critical aspects of the flying environment." This representation is assumed to allow the pilot to make and implement timely decisions with little conscious effort. As an approach for measurement, the author suggests an analogy to benchmarking a computer. Applied to the SA evaluation of competing cockpit designs, this would entail performing "benchmark" missions with each cockpit in a medium fidelity simulator under increasing levels of difficulty. Difficulty of most missions could be increased by requiring higher airspeeds. During the course of these simulated missions a variety of SA relevant data would be collected. Objective data, such as flight performance and reaction to unexpected events, would be combined with subjective data, such as ratings or knowledge elicitation. These data are then weighted and combined by multivariate statistics to produce an aggregate SA score. At the time of the writing of this paper the author had not collected sufficient data to assess the validity and reliability of the approach, but reported that the preliminary research seemed promising.

KEYWORDS: aviation (military), cognitive processes, combat simulation, decision making, definition, measurement, memory probe measures, mental models, performance-based measures, SAGAT, subjective measures

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136. Mogford, R.H. (1994). Mental models and situation awareness in air traffic control. In R.D. Gilson, D.J. Garland, and J.M. Koonce (Eds.), *Situational awareness in complex systems: Proceedings of a CAHFA Conference* (pp. 199-207). Daytona Beach, FL: Embry-Riddle Aeronautical University Press.

The author offers a definition of SA (p. 199): "A proposed definition of situation awareness is, for any given system, the transient contents of awareness as structured and supported by an underlying mental model." In this view the "picture" provided by SA consolidates the sensory impression of the situation for processing by a mental model. A research project was conducted to determine if the quality of an air traffic control student's SA, as measured by a memory probe procedure, is related to the student's overall performance as an air traffic controller, as rated by expert instructors. The memory probe procedure extracted precise information about the location and status of aircraft in a simulated air traffic control scenario following a freeze of the simulation. The students' performance on a variety of parameters were then tested as predictors of the students' ratings by expert air traffic control instructors who observed the students in normal air traffic control simulations. Several of the memory probe variables were found to be statistically related to the instructor ratings. This was interpreted as supporting the contention that good SA of basic aircraft parameters in the airspace forms a basis for good air traffic control in trainees.

KEYWORDS: air traffic control, cognitive processes, definition, measurement, memory probe measures, mental models, training

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137. Morishige, R.I., and Retelle, J. (1985, October). Air combat and artificial intelligence. *Air Force Magazine, 68*(10), 91-93.

This paper reviews the Air Force's Pilot Associate (PA) program. As described by the authors (p. 92), PA "seeks to reverse the trend towards proliferation of systems in fighter aircraft that generate massive amounts of data and dump it on the pilot." The PA will accomplish this by using artificial intelligence to integrate, prioritize, and filter the data and then present the most significant information to the pilot. The main justification for the PA is that it will improve the pilot's SA; that is, the pilot's "awareness of conditions and threats in the immediate surroundings" (p. 92).

KEYWORDS: aviation (military), avionics, definition, pilot aiding

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138. Morrocco, J.D. (1991, March 25). McDonnell F/A-18E/F offers increased range, endurance. *Aviation Week & Space Technology, 134*(12), 25-26.

The article discusses possible design concepts for the F/A-18E/F aircraft. Among the possible changes to the F-18 in the E/F model is the replacement of the 5 X 5 inch multipurpose color display located in the center of the cockpit display area with an 8 X 8 inch flat panel color tactical situation display. This display would be capable of displaying a moving map as well as tactical data. According to the article (p. [illegible]), "Electronics Lead Engineer Bruce K. Fasterling said the system would provide pilots with greater situational awareness by fusing more information together in a single, large display."

KEYWORDS: aviation (military), data fusion, display design, pilot aiding

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139. Mosier, K.L., and Chidester, T.R. (1991). Situation assessment and situation awareness in a team setting. In *Designing for Everyone: Proceedings of the 11th Congress of the International Ergonomics Association* (Volume 1, pp. 798-800). Paris, France: Taylor & Francis.

This paper, along with 4 other SA related papers presented at the Congress, were reprinted in Taylor (1991) and is reviewed under that listing.

KEYWORDS: aviation (civilian), cockpit resource management (CRM), decision making, measurement, performance-based measures, team decision making, team SA

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140. Nagel, D.C. (1988). Human error in aviation operations. In E.L. Wiener and D.C. Nagel (Eds.), *Human factors in aviation* (pp. 263-303). San Diego, CA: Academic Press.

The author discusses the causes and possible remedies for accidents in commercial aviation. As one of the key causes for accidents, the author points to inefficient information transfer to the pilot from displays, crew, and radio communications resulting in breakdowns of pilot situational awareness. The author cites an earlier NASA study of the Aviation Safety Reporting System (ASRS) database that stated that more than 73% of more than 12,000 incidents in commercial aviation were associated with an information transfer problem. The author also suggests that increasing use of automation on the flight deck is producing some problems (p. 300), "As pilots are removed from an active role in flying the aircraft, more and more incidents that can only be termed 'loss of situational awareness' are reported."

KEYWORDS: aviation (civilian), avionics, measurement, pilot error, retrospective measures, subjective measures

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141. Naish, P.L.N. (1990, April). The simulation of localized sounds for improved situational awareness. In AGARD-CP-478, *Situational Awareness in Aerospace Operations* (pp. 12-1 to 12-9). Neuilly Sur Seine, France: Advisory Group for Aerospace Research & Development. (AD-A223939)

Naish reports on two separate studies conducted to look at the potential gain from adding a localization dimension to improve processing of audio cues in the cockpit. The first study was somewhat of a sophisticated Stroop task, where subjects were given four representations of "left, right or centre." One of these words was written on a computer screen, and placed either at the left, right, or centre of the screen. Simultaneously a word (left, right, or centre) was spoken over headphones, and that word would seem to come from either the left, right, or centre of the headphones. Subjects were told which cue to attend to, and performance (RT) with 0, 1, 2, or 3 incongruent cues was analyzed. Naish found that even one incongruent cue significantly increased reaction time for this task; in addition, incongruent cues of the same modality caused a significantly higher increase in reaction time than cues of different modality. In the second study, subjects performing a tracking task carried out a secondary task to identify which of eight LEDs was lit on a hoop around their heads. There were three conditions under which the lights were presented: with no auditory warning, with a centralized bleep, and with a localized warning as to where the LED would be lit. Response times to type in the LED number were significantly faster following localized warnings than following central bleeps. There were considerable inter-subject differences. Naish concludes from these studies that synthetic direction cues, even crude ones, can aid in acquiring spatial information.

KEYWORDS: 3-D audio displays, display design, measurement, performance-based measures, pilot aiding

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142. Nordwall, B.D. (1989, May 8). Pilots sense attitude with peripheral vision using new Garrett display. *Aviation Week & Space Technology, 130*(19), 97, 99.

This article discusses Garrett of Canada's Peripheral Vision Display (PVD). The PVD is a display system that uses a laser to place a horizon line across the entire cockpit display area. It is intended to provide attitude information through peripheral vision and to reduce the probability that spatial disorientation will cause aircraft accidents. A report on helicopter tests conducted by the Naval Air Test Center stated that the PVD improved SA while reducing workload. However, the results of a test program to evaluate the PVD in F-16s were unsatisfactory. The poor results may have been due to difficulties in finding an appropriate mounting location and other physical attributes of the F-16 cockpit. Also, pilots may require specific training on the use of peripheral vision for using the display. Some pilots had a tendency to stare directly at the display.

KEYWORDS: attitude displays, aviation (military), display design, flight test, helicopter, measurement, pilot aiding, subjective measures

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143. Nordwall, B.D. (1990, April 23). Competing ATF proposals to have different avionics suite designs. *Aviation Week & Space Technology, 132*(16), 55-58.

The development of the avionics suite for the Air Force's Advanced Tactical Fighter (ATF) is described. One primary goal of the avionics package is to integrate the use of active and passive sensors to provide the pilot with situational awareness information while keeping detectable emissions to a minimum.

KEYWORDS: aviation (military), avionics, data fusion, pilot aiding

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144. Nordwall, B.D. (1991, June 10). Slow pace on flat displays hinders cockpit advances. *Aviation Week & Space Technology, 134*(23), 61, 64.

The article discusses modern display technologies that can be applied to the military aircraft cockpit. Filling the needs of the military pilot is described as difficult (p. 61): "Complicating the problem for designers is the fact that a pilot needs situational awareness of both 'the big picture' and his personal tactical visual situation." Combining large-area "big picture" displays and helmet-mounted displays is presented as a possible solution. Suitable helmet-mounted displays appear to be within the grasp of current technology, but the big picture display needs further development. However, Air Force simulator tests reportedly demonstrated an almost 50% improvement in fighter pilot kill ratios with the advanced cockpit technologies.

KEYWORDS: aviation (military), big picture displays, combat simulation, display design, helmet-mounted display (HMDs), measurement, performance-based measures, pilot aiding

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145. Nordwall, B.D. (1991, August 5). New data link gave F-14 pilots major advantage in Desert Storm. *Aviation Week & Space Technology, 135*(5), 46-47.

The article reviews a new data linking capability for the F-14 aircraft that was operational during the Gulf War. The digital data link allowed F-14s to directly share tactical information with each other without the need of a intermediary command and control platform. The tactical display showed the location of other F-14s and their radar targets. According to Cdr. Thomas Enright, commander of a F-14 squadron during the war (quoted on p. 46), "The result was fantastic situational awareness." Enright further noted that the system was especially useful for "deconflicting." The term "deconflicting" refers to the process of sorting out the identities of the various aircraft to avoid firing on a friendly aircraft.

KEYWORDS: aviation (military), avionics, data link, display design, flight test, fratricide, pilot aiding, target identification

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146. Nordwall, B.D. (1992, October 19). ITT system will give pilots better threat information. *Aviation Week & Space Technology, 137*(16), 41.

ITT is developing a system to increase pilot SA in Army helicopters. The concept is called the Radar Deception and Jamming (RD&J) system, and is intended to increase SA by providing the pilot with exact information about the location of possible threats. The RD&J system is designed to improve SA by using a three-step process: process data fusion (combining data from on-board sensors with previously programmed knowledge), sensor fusion (using intelligence data from a data link system), and information display (the prioritized threat data will be displayed on a digital terrain map).

KEYWORDS: avionics, data fusion, data link, display design, helicopter, pilot aiding

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147. Nordwall, B.D. (1993, July 5). EW goal is improved situational awareness. *Aviation Week & Space Technology, 139*(1), 59.

The article suggests that electronic warfare (EW) should play a role in future improvements of Air Force pilot SA. These improvements are expected to develop from fusing data from off-board sensors with the aircraft's own sensor information. Programs to test potential sources of information are discussed. The initial goal is to "transmit all the information to a tactical aircraft" (p.59). However, the author also points out that (p.59), "The question of how to present the information without overloading the pilot has not been determined." Two approaches to solving this information presentation problem are mentioned: "feed all information to every aircraft and let the pilot select what he needs" or "have the software for a specific mission automatically select the EW information the pilot would need."

KEYWORDS: aviation (military), avionics, data fusion, data link, pilot aiding

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148. Norman, D.A. (1993). *Things that make us smart.* Reading, MA: Addison-Wesley.

In a discussion of "Distributed Cognition," Norman considers the possible benefits of traditional workplaces relative to proposed improvements. One example discussed is the traditional commercial airliner cockpit with large linked controls versus more modern variants. Norman contends that the traditional cockpit design created unappreciated and perhaps unintended channels of communication that were nonetheless valuable. For example, the large, linked control yokes made it instantly obvious who was controlling the aircraft and what that person was doing. Modern side stick controllers may destroy this channel of communication. Norman associates this with SA (p. 142), "The critical thing about doing shared tasks is to keep everyone informed about the complete state of things. The technical term for this is situation awareness: Each pilot or member of the control team must be fully aware of the situation, of what has happened, what is planned." In general, Norman cautions against making improvements to team environments that seem to improve efficiency, but may inadvertently degrade communication among team members.

KEYWORDS: aviation (civilian), cognitive processes, decision making, team decision making, pilot aiding, team SA

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149. North, D.M. (1990, February 26). Aviation Week editor flies Soviet-based MiG-29 fighter. *Aviation Week & Space Technology, 132*(9), 36-38, 42-45, 48.

The article reviews an evaluation flight of a MiG-29 fighter by an *Aviation Week* editor. For the most part, the author was impressed by the aircraft. However, he had the following comments about the cockpit design (p. 38), "The first impression of the MiG-29 cockpit is that it is comparable to the late-1950s McDonnell Douglas F-4 aircraft with analog instruments with round dials. The MiG-29 instrument panel does not contain the digital and cathode-ray-tube-based displays found in many current Western fighters, such as the F/A-18 and F-15. The instruments and displays suggest that the Soviets do not pay as much attention to situational awareness for the pilot as do Western designers."

KEYWORDS: aviation (military), display design, flight test

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150. North, D.M. (1990, September 24). Aviation Week editor flies top Soviet interceptor. *Aviation Week & Space Technology, 133*(13), 32-35, 38-39, 41.

The article reviews an evaluation flight of the Soviet Su-27 fighter aircraft by an *Aviation Week* editor. The editor was the first American pilot to fly the aircraft. In most respects the Su-27 was judged to be competitive with current U.S. fighters. However, the article notes (p. 35), "But the lack of computer and system integration technology places the Soviet pilot at a disadvantage in terms of situation awareness."

KEYWORDS: aviation (military), avionics, flight test

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151. North, D.M. (1991, March 25). Lavi TD cockpit reflects pilots' combat experience. *Aviation Week & Space Technology, 134*(12), 46-47, 51-53.

Based on an evaluation flight, this article discusses the cockpit design of the Israeli Lavi Technology Demonstrator (TD) largely in terms of effects on pilot SA. The importance and source of SA is stated in no uncertain terms (p. 46), "Situational awareness is one of the most important elements in aerial combat, be it air-to-air or air-to-ground operations. Ultimately, good human engineering is what produces this key feature." More specifically, the aircraft's cockpit integration and display designs are cited as reducing pilot workload and enhancing SA. The editor ranks the TD's success in reducing workload and enhancing SA as far superior to the Soviet Su-27 and MiG-29 designs.

KEYWORDS: aviation (military), avionics, display design, flight test, pilot aiding, workload

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152. North, D.M. (1991, July 15). AMX fills air-to-ground role with room for mission growth. *Aviation Week & Space Technology, 135*(2), 36-37, 40-41, 43-45.

The article reviews an evaluation flight of the AMX aircraft conducted by an *Aviation Week* editor. The AMX is an inexpensive ground attack aircraft developed by an Italian/Brazilian team. SA was used to describe the value of good visibility during landing procedures (p. 44), "The all-around visibility and the 18-deg. over-the-nose visibility allowed for excellent situational awareness in the traffic pattern of the joint military/commercial-use airport."

KEYWORDS: aviation (military), flight test, pilot aiding

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153. North, D.M. (1992, March 23). Airbus pilot training center stresses task-sharing, good communications as key to flying advanced aircraft. *Aviation Week & Space Technology, 136*(12), 63-64.

The article discusses the aircrew integrated management (AIM) course developed by the Airbus Training Center. The course is primarily designed to educate commercial aircrews about cockpit resource management (CRM). The AIM manual defines SA as (p. 64), "an accurate perception of the factors and conditions that affect the aircraft and flight crew during a specific period of time." The course describes barriers, problems in crew coordination, and ineffective communications as contributors to poor crew SA. Descriptions and illustrative exercises of possible ways to build SA are also presented in the course. Eleven clues to loss of SA are listed.

KEYWORDS: aviation (civilian), cockpit resource management (CRM), definition, training

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154. North, D.M. (1992, July 13). A340 handling, cockpit design improve on predecessor A320. *Aviation Week & Space Technology, 137*(2), 38-41, 44-45.

During an evaluation flight of the Airbus A340, an *Aviation Week* editor described the excellent outside visibility and control panel layout as contributing to good pilot SA.

KEYWORDS: aviation (civilian), display design, flight test, pilot aiding

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155. O'Hare, D. (1992). The "artful" decision maker: A framework model for aeronautical decision making. *The International Journal of Aviation Psychology, 2*, 175-191.

The article presents a model of aeronautical decision making (ADM). The model emphasizes the role of situation awareness in decision making and planning. As O'Hare puts it (p. 182), "Most routine decision making arises directly from situation awareness, mapping directly to response selection." Situation awareness also plays a significant role in the review of proposed approaches for improving ADM.

KEYWORDS: cognitive processes, decision aiding, decision making

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156. O'Lone, R.G. (1992, March 23). Boeing works to keep pilot in decision loop on board advanced 777. *Aviation Week & Space Technology, 136*(12), 61.

The article describes the automation strategy being employed by Boeing in the design of the 777 aircraft. Brian Kelly, a Boeing 777 flight deck specialist is quoted as describing the approach as follows (p. 61), "We try to automate in such a way that the pilot remains in the decision loop and the pilot's awareness of the situation is preserved and even enhanced." This goal is accomplished by using an automation strategy that requires the automation to inform the crew of planned action and getting the crew consent before executing it. The hope is to take some workload out of the tasks but to keep the pilot in the loop.

KEYWORDS: aviation (civilian), avionics, data link, decision aiding, decision making, pilot aiding, workload

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157. Oliver, J.G. (1990). *Improving situational awareness through use of intuitive pictorial displays* (SAE Technical Paper Series No. 901829). Warrendale, PA: Society of Automotive Engineers.

This paper is primarily concerned with improving SA to reduce the probability of errors in commercial airplanes. It adopts a definition of SA from the Aerospace Glossary for Human Factors Engineers (cited on p. 1), "keeping track of the prioritized significant events and conditions in one's environment." The author contends that the loss of SA in the airline cockpit is a recent development that developed "in direct proportion with the ever-dwindling demand for the crew to directly control the flight situation" (p. 2). The author suggests that the vast majority of attempts to improve SA have consisted of procedural changes to force the crews to handle more information in the hope that they will understand and retain it. In assessing these efforts, the author states (p.3): "While the industry campaign to improve situational awareness through procedural modification has been partially successful, it can never be totally successful. By design, procedures force the crews to perform a seemingly endless series of make-work tasks that lead to boredom and complacency, which, in turn, lead to a loss, not a gain, of situational awareness." As an alternative, the use of intuitive pictorial displays is advocated as a means to enhance SA. Several display systems are discussed. For example, the Navigation display is cited as an example of a display that has enhanced SA, while the Electronic Flight Instruments (EFIS) display is cited as an example of a display that failed to enhance SA. The author concludes (p. 7): "What is needed if we really are interested in greater situational awareness, is not additional lip service, but a commitment from industry to provide pictorial displays in today's cockpits. Until we do, we should expect the incidence of accidents/incidents, attributed to the crew's loss of situational awareness, to continue essentially unchanged."

KEYWORDS: aviation (civilian), avionics, definition, display design, pilot aiding, pilot error

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158. Parrish, R.V., Busquets, A.M., and Williams, S.P. (1990). Recent research results in stereo 3-D pictorial displays at Langley Research Center. In *Proceedings of the IEEE/AIAA/NASA 9th Digital Avionics Systems Conference* (pp. 529-539). New York: Institute of Electrical and Electronics Engineers.

This paper summarizes the results of several studies conducted at NASA - Langley Research Center on the possible application of stereoscopic 3-D pictorial displays. Summarizing the implications of the studies, the authors state (p. 529): These studies demonstrated increased pilot/vehicle performances through situational awareness enhancements of pictorial displays with stereopsis cuing." The improvement of SA was generally inferred from the improvement in some performance-based metric, such as deviation from a desired path or stability of a hover. Although it is stated that subjective reactions supported the SA improvement as well, no explanation of what subjective measures were collected is offered. The studies were conducted in a variety of simulated flight tasks. The tasks studied included commercial aviation landing patterns, hovering a helicopter, and using helmet-mounted displays (HMDs). The technical issues surrounding the use of stereoscopic displays are also discussed.

KEYWORDS: aviation (civilian), display design, helicopter, helmet-mounted displays (HMDs), measurement, performance-based measures

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159. Perrott, D.R., Sadralodabai, T., Saberi, K., and Strybel, T.Z. (1991). Aurally aided visual search in the central visual field: Effects of visual load and visual enhancement of the target. *Human Factors, 33*, 389-400.

The use of 3-D audio to enhance performance in a laboratory visual search task was investigated. It was argued that 3-D audio combined with a head-coupled display system, "could improve situational awareness by informing that critical visual information outside the current visual field is available" (p. 390). The results supported this suggestion. Aurally guided search improved detection of targets in the visual periphery, especially when large numbers of distractors were present.

KEYWORDS: 3-D audio displays, display design, measurement, performance-based measures, target identification

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160. Pettitt, M.A. (1993). Cockpit crises and decision making: Implications for pilot training. In *Proceedings of the Seventh International Symposium on Aviation Psychology* (Volume 1, pp. 221-225). Columbus: The Ohio State University.

The paper explores the psychosocial dynamics of flight crews facing a crisis situation. According to the author, a crises is characterized by a change in the environment that threatens the goals of the team, generally involves substantial risk, and generally allows little time for decision making. Data was collected from a survey distributed to over 600 Los Angeles-based airline pilots. One hundred eighty-five of the surveys were returned. The survey form described an example crises situation and then asked the pilots to rate the crises characteristics of the scenario on numerous dimensions using a Likert-like scale. The results indicated that a crucial component of the perception of crisis was the sense of urgency associated with a lack of time. The author related this finding to SA (p. 223), "The results of this study suggest that it would be beneficial to expand the concept of situational awareness to include (a) the concept of crisis and (b) the accurate assessment of decision time available in critical situations."

KEYWORDS: aviation (civilian), cognitive processes, decision making, definition, measurement, questionnaire/survey data, subjective measures, team decision making, team SA

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161. Pew, R.W. (1994a). Situation awareness: The buzzword of the '90s. *CSERIAC Gateway, 5*(1), 1-4.

The author expresses a certain skepticism about what is meant by the term SA and whether the concept really adds anything beyond the usual consideration of human performance requirements in a system. Despite reservations, the author addresses SA because it has become (p. 2) "the buzzword of the '90s" (having replaced "workload"). Starting with the definitional issue, the author expresses an affinity for Endsley's (1988a) definition as a one sentence summary. However, it is suggested that definitions of SA should begin with a careful consideration for the definition of what constitute a situation. A working definition of a situation is offered (p. 2): "A situation is a set of environmental conditions and system states with which the participant is interacting that can be characterized uniquely by its priority goals and response options." Given a situation, the SA requirements must be defined to produce a standard against which human performance can be measured. It is proposed that the standard should be described at three levels: (1) an *abstract ideal* (the full set of potentially useful information), (2) a *physically realizable ideal* (a subset of the abstract ideal that considers the constraints imposed by a real crew station), and (3) a *practically realizable ideal* (a subset of the physically realizable ideal that considers the constraints of the human performance capacities and limitations). Training and selection are suggested as ways to reach the physically and practically realizable ideals, while crew station design and implementation can potentially be used to move closer to the abstract ideal. The author also differentiates between situation awareness as a product, and the process of situation assessment which produces the awareness. Finally, the author suggests research strategies involving selection, training, or design that might be successful in determining whether SA is a useful concept that can be differentiated from operational human performance.

KEYWORDS: definition, display design, individual differences, measurement, training

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162. Pew, R.A. (1994b). An introduction to the concept of situation awareness. In R.D. Gilson, D.J. Garland, and J.M. Koonce (Eds.), *Situational awareness in complex systems: Proceedings of a CAHFA Conference* (pp. 17-23). Daytona Beach, FL: Embry-Riddle Aeronautical University Press.

This paper covers much of the same ground as the Pew (1994a) paper regarding definition and the need for standards in SA assessment, albeit in more detail on some issues and with some changes in terminology. The author includes a more detailed discussion of how active memory processes play a vital role in SA. Also, the author identifies a question that he considers critical for any SA researcher to address in order to justify committing significant research effort to SA (p. 22): "This question concerns the generality of the concepts associated with SA. Either (1) there are design principles and general individual abilities to be discovered that are applicable across specific devices and tasks, or (2) every task and device is unique and it only makes sense to select, train and design to promote the crew's performance with specific display configurations and response requirements." In assessing his own belief regarding this question, the author states (p. 23): "For the moment, I come down in between. I believe it is not possible to define SA independently of an understanding of the SA requirements of context-specific situations. But I also believe that there may be skills in doing this that are more general and that are worthy of evaluation."

KEYWORDS: cognitive processes, definition, display design, individual differences, measurement, training

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163. Picart, J.A. (1991, May). Expert warfighters with battlefield vision. *Military Review, 71*(5), 51-60.

The paper does not specifically discuss SA. However, the concept of "battlefield vision" seems to be unmistakably similar to SA. The US Army Field Manual 22-103 defines battlefield vision as, "the ability to intuitively sense the significance of battlefield events for future actions" (cited by Picart, p. 51). The author describes the relationship of battlefield vision to pattern recognition and expertise among other topics. The author also describes the "decision support template" as an aid for battlefield decision making and proposes how the training of officers should be organized to develop commanders with good battlefield vision.

KEYWORDS: battlefield SA, cognitive processes, decision aiding, decision making, expertise, training

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164. Pritchett, A., and Hansman, R.J. (1993). Preliminary analysis of pilot ratings of "party line" information importance. In *Proceedings of the Seventh International Symposium on Aviation Psychology* (Volume 1, pp. 360-366). Columbus: The Ohio State University.

The authors hypothesized that data-linked air traffic control might degrade SA in the commercial airline cockpit. This hypothesis was based on the loss of "party-line information" (PLI), the information that any pilot can pick up by listening to air traffic control's communications with other aircraft. Over 4,000 surveys were sent out to pilots to assess their opinions on this topic. Survey forms were distributed to a wide variety of pilot types; including General Aviation, Commuter Airline, Major Airline, Air Force, and Navy pilots. At the time of the writing of the article 715 completed surveys had been returned and used in the analyses. One key question on the survey was, "What does the 'Big Picture' mean to you?" The most common response concerned the location of other aircraft. In order, this was followed by knowledge of weather, predicting future events, and communication. Summarizing the implications of their results, the authors conclude (p. 363), "traffic and weather information should be given high priority in the development of 'Party Line' compensation strategies."

KEYWORDS: air traffic control, aviation (civilian), avionics, data link, measurement, pilot aiding, questionnaire/survey data, subjective measures

165. Rantanen, E. (1994). The role of dynamic memory in air traffic controllers' situation awareness. In R.D. Gilson, D.J. Garland, and J.M. Koonce (Eds.), *Situational awareness in complex systems: Proceedings of a CAHFA Conference* (pp. 209-215). Daytona Beach, FL: Embry-Riddle Aeronautical University Press.

Rantanen equates the concept of SA with the "picture" that air traffic controllers must maintain to perform their tasks. The "picture" is defined as follows (p. 209): "The air traffic controller's picture is a mental model of the airspace architecture, layout of the runways at airports, rules and standard procedures regulating the conduct of flights, and positions, flight data, and performance characteristics of the aircraft operating within this system. Also included in the picture are numerous other factors relevant to the traffic situation, such as the weather, operational status of navigation aids and the ATC equipment, staffing, and sectorization within the facility, and possible irregularities within these." Within this framework, Rantanen discusses the role of dynamic memory processes in maintaining the air traffic controller's SA. This leads to the conjecture that unless the application of automation to air traffic control is carefully guided it might reduce workload by eliminating the dynamic memory processing that is essential to good SA.

KEYWORDS: attention, air traffic control, cognitive processes, definition, mental models, multiple resource theory, workload

166. Redding, R.E. (1992). Analysis of operational errors and workload in air traffic control. In *Proceedings of the Human Factors Society 36th Annual Meeting* (Volume 2, pp. 1321-1325). Santa Monica, CA: Human Factors Society.

The paper reviews a major curriculum redesign effort undertaken to improve the training of enroute air traffic controllers. A cognitive task analysis of current en route controllers suggested that failure to maintain SA was the primary cause of air traffic control errors. Failure to maintain SA was linked to inappropriate mental models guiding task performance. Proposals for the modification of air traffic control training to improve SA are discussed.

KEYWORDS: air traffic control, cognitive processes, expertise, measurement, mental models, retrospective measures, subjective measures, training

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167. Redding, R.E., and Cannon, J.R. (1992). Expertise in air traffic control (ATC): What is it, and how can we train for it? In *Proceedings of the Human Factors Society 36th Annual Meeting* (Volume 2, pp. 1326-1330). Santa Monica, CA: Human Factors Society.

This paper presents further discussion of some of the issues raised in Redding (1992). In this paper, the nature of expertise within the air traffic control domain is the main focus. Maintaining SA is considered a key component of expertise in air traffic control.

KEYWORDS: air traffic control, cognitive processes, expertise, measurement, mental models, performance-based measures, questionnaire/survey data, retrospective measures, subjective measures, training

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168. Regal, D.M., Rogers, W.H., and Boucek, G.P. (1988). *Situational awareness in the commercial flight deck: Definition, measurement, and enhancement* (SAE Technical Paper Series No. 881508). Warrendale, PA: Society of Automotive Engineers.

This paper provides a description and breakdown of elements involved in SA for the commercial flight environment. First, the authors state that SA can be defined at several levels. At the highest level, they believe SA "simply means that the pilot has an integrated understanding of factors that will contribute to the safe flying of the aircraft under normal or non-normal conditions" (p. 1). SA is broken down into components of spatial awareness, awareness of environment, awareness of aircraft performance, aircraft systems awareness, and crew awareness, with examples provided for each component. Several benefits can be gained from enhancing SA, and these are listed and discussed. They are improved safety, reduced workload, enhanced pilot performance, an expanded range of operation, and better decision-making. As regards measurement, the authors state, "We believe that in order for [SA] to serve as a flight deck design criterion, its measurement must be quantified, standardized, and validated" (p. 3). Direct measurement of SA via asking a series of questions is advocated, along with measurement of pilot performance in simulator and laboratory settings. Finally, enhancing SA through better flight deck design, air crew coordination, crew training, and artificial intelligence aids is recommended.

KEYWORDS: aviation (civilian), cockpit resource management (CRM), definition, measurement, memory probe measures, performance-based measures, pilot aiding, workload

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169. Rodgers, M.D., and Duke, D.A. (1994). SATORI: Situation assessment through the re-creation of incidents. In R.D. Gilson, D.J. Garland, and J.M. Koonce (Eds.), *Situational awareness in complex systems: Proceedings of a CAHFA Conference* (pp. 217-225). Daytona Beach, FL: Embry-Riddle Aeronautical University Press.

This article discusses the development of the Situation Assessment through the Re-Creation of Incidents (SATORI) system. The SATORI system uses the data that is already recorded within the air traffic control system to recreate the screen displays that existed during any specified incident. It is intended to allow close study of and operational error (OE) incidents that occur. Numerous potential uses for the SATORI system are discussed, including the use as a research tool to investigate the effects of proposed automation on air traffic controller SA.

KEYWORDS: air traffic control, training

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170. Rouse, D.M., and Hummel, T.C. (1987). *The pilot's associate: Enhancing situational awareness through cooperating expert systems* (SAE Technical Paper Series No. 871896). Warrendale, PA: Society of Automotive Engineers.

The authors discuss the design of the Pilot's Associate (PA) system. PA is a program, funded by the Defense Advanced Research Projects Agency (DARPA) and managed jointly with the US Air Force Wright Aeronautical Laboratory. PA is described by the authors as (p. 1), "a network of cooperating expert systems designed to enhance pilot situational awareness by assisting the pilot with information management and aircraft control." PA uses five cooperating subsystems (i.e., Mission Planner, Tactics Planner, Situation Assessment, System Status, and Pilot-Vehicle Interface) and an executive operating system. The goals for PA include managing (but not necessarily reducing) pilot workload, converting raw data into prioritized information, communicating this information to the pilot, and advising the pilot.

KEYWORDS: aviation (military), avionics, decision aiding, pilot aiding, workload

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171. Salas, E., Stout, R.J., and Cannon-Bowers, J.A. (1994). The role of shared mental models in developing shared situational awareness. In R.D. Gilson, D.J. Garland, and J.M. Koonce (Eds.), *Situational awareness in complex systems: Proceedings of a CAHFA Conference* (pp. 297-304). Daytona Beach, FL: Embry-Riddle Aeronautical University Press.

This article extends the SA concept from the more typical individual performer setting to team environment. The concepts of mental models and, more specifically, shared mental models are discussed. After reviewing some relevant literature the authors conclude (p. 300): "Summarizing the results of both literature related to shared mental models and performance and team situational awareness and performance, the following conclusions can be made: 1) mental models are important for individual situational awareness; 2) shared mental models, which allow each member to form adequate explanations and expectations of task and team actions, are important to team performance; and 3) team situational awareness is important to team performance." A cognitive model is then used to describe how team SA contributes to team performance.

KEYWORDS: cognitive processes, mental models, team SA

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172. Sarter, N.B. (Panel Organizer), and Woods, D.D. (Panel Chair) (1990). Situation awareness in the advanced commercial aircraft cockpit. In *Proceedings of the Human Factors Society 34th Annual Meeting* (Volume 1, pp. 21-25). Santa Monica, CA: Human Factors Society.

This set of abstracts summarizes a panel session. This panel was primarily concerned with the potential impact of automation on SA and the lack of an agreed-upon definition and conceptual foundation for SA. Six abstracts follow the introduction: Rolf Braune (*Automation in Commercial Transport Airplanes: The Role of Situational Awareness*); Everett Palmer (*Crew Situation Awareness*); William Rogers (*What Implications does Human-Centered Automation have for Situational Awareness Requirements?*); Nadine Sarter (*Situation Awareness - A Critical but Ill-Defined Phenomenon*); Christopher Wickens, Kelly Harwood, Anthony Andre, and Anthony Aretz (*Situation Awareness, Visual Momentum, and Frames of Reference*); and Earl Wiener (*Barriers to Situational Awareness in the Cockpit and Possible Intervention Strategies*).

KEYWORDS: aviation (civilian), avionics, cockpit resource management (CRM), cognitive processes, definition, display design, pilot aiding, team SA

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173. Sarter, N.B., and Woods, D.D. (1991). Situation awareness: A critical but ill-defined phenomenon. *The International Journal of Aviation Psychology, 1,* 45-57.

The article is very concerned with adding rigor to the concept of situation awareness. The considerable conceptual overlap between situation awareness and mental models is noted, but a distinction is drawn between these concepts. The authors point out that (p. 49), "Mental models refer to systems or devices that can be represented by a finite number of elements and algorithms, whereas situation awareness is about a continuously changing open system involving a large variety of unpredictable and interacting agents and devices." This distinction also illustrates the authors' concept of the central role played by temporal factors in situation awareness. The complexity of the mental models involved in situation awareness evolving dynamically over time lead to methodological concerns about approaches that have been tried for measuring situation awareness. The authors fear that attempts to assess situation awareness via specific probes for information may be "missing the phenomena" of overall situation awareness. More detailed analysis of the contents of memory, such as that acquired through Endsley's SAGAT, are considered to be potentially troublesome because of their intrusiveness and because the freezing procedure may not (p.54) "provide data about the natural character and occurrence of situation awareness." Situation awareness measurement procedures that rely on debriefing procedures after an event were considered to be flawed because they will not allow access to unconscious information that could have been brought into awareness if the appropriate triggering conditions were present. Instead of these approaches the authors suggest that investigation of situation awareness "requires the staging of complex dynamic situations and the development of less-intrusive in-flight probing techniques to assess the pilot's ability to adequately, and in the most timely manner, receive and integrate flight-related information" (p. 55).

KEYWORDS: cognitive processes, definition, measurement, memory probe measures, mental models, performance-based measures, SAGAT

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174. Sarter, N.B., and Woods, D.D. (1992). Pilot interaction with cockpit automation: Operational experiences with the flight management system. *The International Journal of Aviation Psychology, 2,* 303-321.

The authors examined the impact of advanced automation on situation awareness and performance in the Boeing B-737-300. In specific, the pilots' interactions with the flight-path control functions of the Flight Management System (FMS) were studied. Two studies were conducted: (1) a survey study of B-737-300 pilots, and (2) observations of pilots undergoing transition training in a simulator. Discussing the results of both studies, the authors report (p. 316), "The corpus of reported and observed difficulties indicates that pilots can lose situation awareness (Sarter & Woods, 1991) concerning FMS status and behavior." Further, the authors point out that individual pilots develop their own limited and idiosyncratic strategies for dealing with the FMS and these different strategies may cause problems among the team members in trying to maintain their SA. The authors suggest that the training of pilots could be improved (p. 320), "If pilots were provided with an overall mental representation of the functional structure of the FMS, they would be better able to manage and utilize the automated systems in unusual or novel situations."

KEYWORDS: aviation (civilian), avionics, cognitive processes, measurement, mental models, questionnaire/survey data, subjective measures, team SA, training

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175. Sarter, N.B., and Woods, D.D. (1994a). Pilot interaction with cockpit automation II: An experimental study of pilots' model and awareness of the flight management system. *The International Journal of Aviation Psychology, 4,* 1-28.

This article expands on the authors' analysis of the Flight Management System (FMS) started in their 1992 paper by incorporating the SA measurement procedures discussed in their 1991 paper. The authors used probe questions designed to assess the quality of 20 airline pilots' mental models of the operation of the FMS. These probe questions were presented during the performance of a simulated flight in a B-737-300 part-task trainer. Based on pilot performance and responses to the probe questions, the authors reported that (p. 21), "most of the difficulties in pilot-automation interaction are related to a lack of mode awareness and to gaps in pilots' mental models of the functional structure of the automation." In general, the pilots had a difficult time managing the automation in several simulated non-normal time-critical events. The authors suggest that this lack of understanding of the operation of the FMS is inconsistent with the maintenance of effective SA. Causes of and possible solutions for improving the pilots' SA in this type of environment are discussed.

KEYWORDS: aviation (civilian), avionics, cognitive processes, measurement, memory probe measures, mental models

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176. Sarter, N.B. and Woods, D.D. (1994b). "How in the world did I ever get into that mode?" Mode error and awareness in supervisory control. In R.D. Gilson, D.J. Garland, and J.M. Koonce (Eds.), *Situational awareness in complex systems: Proceedings of a CAHFA Conference* (pp. 111-123). Daytona Beach, FL: Embry-Riddle Aeronautical University Press.

The authors discuss one type of SA, called "mode awareness," as a problem being experienced with applications of advanced automation in the cockpits of airline aircraft. Mode awareness refers to the knowledge of an operator concerning which mode a complex system is currently in, and the implications of being in that mode on system behavior. The authors' interpretation of mode awareness makes use of the concept of mental models, especially focusing on the possible causes and effects of "buggy" mental models. In the course of the discussion, the authors address the issue of a definition for SA (p. 120): "First, extended efforts to develop the 'right' definition or a consensus definition of situation (and mode) awareness will probably not be constructive. Rather, the term 'situation awareness' should be viewed as just a label for a variety of cognitive processing activities that are critical to dynamic event-driven and multi-task fields of practice." Among the cognitive processing domains suggested as related to SA the areas of attention and memory processes are prominent. The authors also address the issue of measuring SA. They divide the potential measures of SA into three main areas: subjective ratings, explicit performance measures, and implicit performance measures. Subjective ratings (such as SART) and explicit performance measures (such as SAGAT) are assessed as having limited utility due to conceptual and/or practical flaws. Implicit performance measures, while not without some shortcomings, are presented as a viable approach for assessing SA.

KEYWORDS: attention, aviation (civilian), avionics, cognitive processes, definition, implicit measures, measurement, memory probe measures, mental models, subjective measures, SAGAT, SART

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177. Schwartz, D. (1989). Training for situational awareness. In *Proceedings of the Fifth International Symposium on Aviation Psychology* (Volume 1, pp. 44-54). Columbus: The Ohio State University.

This article is oriented towards pilots and designers of pilot training programs. Schwartz's objective is to outline the "elements which contribute to taking correct action in the cockpit." He presents "the safety window" as the time period and airspace surrounding approach, landing, and takeoff, where accidents are most likely to occur. The author breaks SA down into five contributing factors (experience and training, physical flying skills, spatial orientation, health and attitude, and cockpit management), and talks about each in detail. These elements should all be included in any SA pilot training program. Schwartz points out the importance of identifying links in "the error chain" of events as an essential part of cockpit management training; the error chain is the sequence of events which, unless interrupted, often leads to accidents. If a crewmember can identify and correct a situation in progress which is characterized by one of Schwartz's 11 signs that an error chain is underway, an accident may be averted. Schwartz recommends all flight crew training programs include this type of information.

KEYWORDS: aviation (civilian), cockpit resource management (CRM), pilot error, training

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178. Schwartz, D. (1993, May) Training for situational awareness. *Air Line Pilot, 62*(4), 20-23.

This appears to be a republication of the Schwartz (1989) paper, and is reviewed under that listing.

KEYWORDS: aviation (civilian), cockpit resource management (CRM), pilot error, training

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179. Scott, W.B. (1989, April 17). Falcon Eye Flir, GEC helmet aid F-16 mission flexibility. *Aviation Week & Space Technology, 130*(6), 34-36, 41, 45-47.

The Falcon Eye system is an infrared sensor mounted in front of an F-16 cockpit. The sensor is placed in a ball-shaped unit that can rotate to aim the sensor in different directions. The direction of the sensor is determined by a system that detects movements of the pilot's head. The sensor points in the same direction as the pilot's head. Imagery from the sensor is presented by a helmet-mounted display. The author argues that Falcon Eye "adds an excellent degree of tactical flexibility and night situational awareness by allowing the pilot to look in any direction" (p. 35). The system is intended to increase the potential for carrying out close air support and battlefield interdiction (CAS/BAI) missions.

KEYWORDS: air-to-ground mission, aviation (military), avionics, display design, flight test, helmet-mounted displays (HMDs), pilot aiding, target identification

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180. Scott, W.B. (1990, April 30). F-15E's night attack capability assessed in low-level flight. *Aviation Week & Space Technology, 132*(18), 36-38, 43, 46.

An *Aviation Week* editor flew with an Air Force pilot to observe the use of the F-15E as a night attack aircraft. The editor flew in the back-seat weapons systems officer (WSO) station. SA was mentioned in a discussion of one of the displays the WSO could select for one of the multifunction CRT displays. The WSO had the option of monitoring the head-up display (HUD) symbology and the Forward-Looking Infrared (FLIR) video. The editor stated that (p. 43), "I found that a periodic quick glance at this display provided some of the basic situational awareness cues one normally would get by looking outside the cockpit during a day-time flight."

KEYWORDS: air-to-ground mission, aviation (military), display design, flight test

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181. Scott, W.B. (1991, June 3). 777's flight deck reflects strong operations influence. *Aviation Week & Space Technology, 134*(22), 52, 57-58.

The Boeing 777 cockpit will incorporate fly-by-wire controls (a first for Boeing), new color liquid crystal displays, and modern avionics (including data-link with air traffic control). While putting together these elements, the Boeing engineers' first objective is to (p. 52), "optimize pilots' situational awareness, both inside and outside the aircraft."

KEYWORDS: aviation (civilian), avionics, data link, pilot aiding

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182. Scott, W.B. (1992, February 3). F/A-18D night attack features boost Marine air effectiveness. *Aviation Week & Space Technology, 136*(5), 38-42.

An *Aviation Week* editor flew with a Marine pilot to observe how the Marines were using night-vision goggles (NVGs) and Forward-Looking Infrared (FLIR) sensors to use the F-18D as a night attack aircraft. SA was mentioned in interpreting the effect of the NVGs limited field-of-view on low altitude flying (p. 41), "Human factors research has determined that low-altitude situational awareness depends a great deal on visual cues from peripheral vision." These peripheral vision cues are missing from the NVGs. To compensate for the lack of peripheral vision, the training of the Marine F-18D pilots emphasizes that pilots must keep their heads moving and not fixate on one thing in the outside world.

KEYWORDS: air-to-ground mission, aviation (military), display design, flight test, pilot aiding, training

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183. Scott, W.B. (1992, February 10). New F/A-18C/D software to integrate sensor inputs, reduce pilot workload. *Aviation Week & Space Technology, 136*(6), 46-47.

The Multi-Source Integration (MSI) software package is being tested for possible use in upgrading the F-18 aircraft avionics for air-to-air combat. There are two main components to the software: (1) new mission computer algorithms to merge data from several onboard sensors to present a single "trackfile" for each target, and (2) four new display formats to present the information (including a "situation awareness format"). The outcome of these upgrades is described by Lt. Cdr. Jeff Crutchfield, chief test pilot, as (p. 46), "The pilot gets improved detection, track continuity, better [weapon] accuracy, and improved situational awareness."

KEYWORDS: air-to-air mission, aviation (military), avionics, data fusion, data link, display design, pilot aiding

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184. Scott, W.B. (1992, March 23). Douglas uses MD-11 cockpit success as springboard for designing MD-12. *Aviation Week & Space Technology, 136*(12), 58-59.

The article describes the philosophy and process used by McDonnell Douglas to guide the implementation of automation in the MD-12 aircraft. The overall philosophy is described as "keeping the pilot in the loop." As automatic systems sense new conditions and adjust for them, the pilot is notified of these actions. It is stated that (p. 59), "Douglas engineers said that this approach ensures pilot situational awareness and the ability to always override automatic functions." Effort is also taken to ensure that visual, aural, and tactile cues of what is happening are maintained. However, there was still some concern that the operation of the aircraft required too much "head-down" time. Flight crews have argued that more functions should be implemented through the glareshield panel display.

KEYWORDS: aviation (civilian), avionics, display design, pilot aiding

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185. Scott, W.B. (1993, June 7). Second-generation Flirs enhance night attack systems. *Aviation Week & Space Technology, 138*(23), 143-145.

The article reviews the Falcon Knight system. The Falcon Knight system uses two head-steered Forward- Looking Infrared (Flir) sensors that present outside imagery on helmet-mounted displays. The Flir information is integrated with the on-board fire-control radar. This system was contrasted to night attack systems based on external pod-carried units. One of the main advantages of the Falcon Knight system was felt to be improved SA, especially during attacks. For example, Falcon Knight enabled pilots to launch Maverick Missiles two seconds sooner than they would in an unequipped F-16.

KEYWORDS: air-to-ground mission, aviation (military), avionics, data fusion, display design, flight test, helmet-mounted displays (HMDs), measurement, performance-based measures

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186. Secrist, G.E., and Hartman, B.O. (1993, May). *States of awareness I: Subliminal perception relationship to situational awareness* (Tech. Report No. AL-TR-1992-0085). Brooks Air Force Base, TX: Armstrong Laboratory. (AD-A267249)

As part of a search for a conceptual foundation for SA, the authors examined many areas of the behavioral sciences. Among the areas that seemed to have a relevant relationship to SA was the topic of subliminal perception. As described by the authors (p. 1), "The concept of subliminal perception concerns the notion that individuals can acquire, analyze, process, and be affected by sensory stimuli below the level of conscious awareness." The bulk of the report is a detailed review of the theoretical concepts associated with subliminal perception, the empirical data used to support the notion of subliminal perception, and the critiques of the notion. Based on this review, the authors conclude that "subliminal perception and related subconscious information acquisition and processing capabilities are an untapped reservoir of human potential" (p. 46). The authors argue that subliminal perceptual capabilities could potentially be developed in individuals and discuss how such development would enhance SA and performance.

KEYWORDS: cognitive processes, review paper

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187. Secrist, G.E., and Hartman, B.O. (1993). Situational awareness: The trainability of the near-threshold information acquisition dimension. *Aviation, Space, and Environmental Medicine, 64*, 885-892.

Following up on the notions presented in their Hartman and Secrist (1991) paper, the authors present the results of an experiment to examine the trainability of near-threshold information processing. The experiment used three different tasks that involved the detection, recognition, or identification of symbols that were presented for duration of either 33 msec or 67 msec. Results showed that performance on these tasks improved with practice, and the improvement was much quicker with the 67 msec presentations. There was no test of whether this training transferred to another task environment, however. As the authors themselves state (p. 891), "We have demonstrated only that a training technique derived from our conceptual structure for situational awareness has shown training effects and that such effects are internally consistent."

KEYWORDS: cognitive processes, measurement, performance-based measures, training

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188. Selcon, S.J. and Taylor, R.M. (1990, April). Evaluation of the situational awareness rating technique (SART) as a tool for aircrew systems design. In AGARD-CP-478, *Situational Awareness in Aerospace Operations* (pp. 5-1 to 5-8). Neuilly Sur Seine, France: Advisory Group for Aerospace Research & Development. (AD-A223939)

The Situational Awareness Rating Technique (SART) was developed by Taylor as a means of evaluating aircrew systems designs. The ten dimensional SART scale consists of three domains (Demand on Attentional Resources, Supply of Attentional Resources, Understanding) covering ten constructs (such as Variability of Situation under "Demand," Concentration under "Supply," and Information Quantity under "Understanding"). This paper discusses the three experiments conducted to evaluate the SART. Study I was a multiple task compatibility study, investigating left/right hemisphere-specific tasks in competition for attentional resources. Study II investigated attention-switching capabilities when subjects were presented with different attitude references during emergency attitude recovery. Study III focused on the reaction times of subjects when presented with visual, auditory or both type warning icons describing "Warning" or "Caution" situations. The general discussion provides support for validating the SART methodology.

KEYWORDS: attention, attitude displays, cognitive processes, display design, measurement, performance-based measures, SART, subjective measures

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189. Selcon, S.J., and Taylor, R.M. (1991). Decision support and situational awareness. In *Designing for Everyone: Proceedings of the 11th Congress of the International Ergonomics Association* (Volume 1, pp. 792-794). Paris, France: Taylor & Francis.

This paper, along with 4 other SA related papers presented at the Congress, were reprinted in Taylor (1991) and is reviewed under that listing.

KEYWORDS: cognitive processes, decision aiding, decision making, pilot aiding

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190. Selcon, S.J., Taylor, R.M., and Koritsas, E. (1991). Workload or situational awareness?: TLX vs. SART for aerospace system design evaluation. In *Proceedings of the Human Factors Society's 35th Annual Meeting* (Volume 1, pp. 62-66). Santa Monica, CA: Human Factors Society.

This experiment contrasted subjective situation awareness ratings (10-D and 3-D SART) to subjective workload ratings (NASA-TLX). Twelve RAF pilots participated by watching videotaped simulations of air combat. The videotaped missions were previously ranked to represent differing levels of task difficulty/attentional demands. Both types of ratings were sensitive to changes in task demands. However, SART was sensitive to experience differences that NASA-TLX failed to detect. Overall, the results suggest overlap in the subjective experiences of situation awareness and mental workload.

KEYWORDS: attention, cognitive processes, measurement, SART, subjective measures, workload

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191. Selcon, S.J., Taylor, R.M., and Shadrake, R.A. (1991, June). *Information processing advantages of multiple sources of cockpit information* (Institute of Aviation Medicine Report No. 672). Farnborough, UK: RAF Institute of Aviation Medicine.

This document describes three studies which evaluated the processing of information presented by means of redundant sources. The purpose of these studies of "redundancy gain" was to explore the comprehension benefits in the theoretical framework as well as the context of aircrew system design. The first experiment used a bi-modal (visual and verbal) presentation of numbers to evaluate cross-modal integrality. The second used colors, words, and a combination of the two to determine redundancy gains at the "level of comprehension." The last experiment investigated performance gains related to warning/caution icons and verbal messages; the Situational Awareness Rating Technique (SART) was used to measure the depth of understanding.

KEYWORDS: cognitive processes, display design, measurement, performance-based measures, pilot aiding, SART, subjective measures

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192. Selcon, S.J., Taylor, R.M., and Shadrake, R.A. (1992). Multi-modal cockpit warnings: Pictures, words, or both? In *Proceedings of the Human Factors Society 36th Annual Meeting* (Volume 1, pp. 57-61). Santa Monica, CA: Human Factors Society.

The authors examined the potential benefits of linking meaningful pictorial icons and auditory signals together in multi-modal warnings. The results indicated that the combination of signals was responded to more quickly than unimodal signals. The 3-Dimensional Subjective Assessment Rating Technique (SART) was also used to assess the effects of the multimodal signals. The subjects ratings suggested that there was both a reduction of workload and an increase in understanding when the multimodal signals were used. The authors also proposed a formula for combining the three raw SART scale values into a single overall calculated SA rating. This formula consisted of subtracting the Supply rating from the Demand rating, and then subtracting the difference from the understanding rating [SA(c)=Understanding-(Demand-Supply)]. The SA(c) score was also sensitive to the benefits of multimodal warning signals.

KEYWORDS: cognitive processes, display design, measurement, performance-based measures, pilot aiding, SART, subjective measures, workload

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193. Shaw, R.L. (1985). *Fighter combat: Tactics and maneuvering*. Annapolis, MD: Naval Institute Press.

During the course of discussing air combat, SA is mentioned repeatedly as one contributor to success. In fact, the trend towards adding electronic aids to the cockpit that started in World War II and continues unabated is interpreted within a SA framework (p. 291), "All of this electronic technology is intended to increase the situational awareness of friendly forces in battle and to deny such valuable information to the enemy. The incredible attention electronics technology has received in recent years is a clear indication of the importance of situational awareness in air combat." Not surprisingly, SA is expected to be harder to maintain as the number of aircraft involved in combat increases, regardless of whether the aircraft are friendly or enemy. However, SA (actually "degree of confidence in situation awareness") is described as one of the vital components of a tactical situation that should be considered during the selection of tactics (pp. 367-368). Also, some tactics are discussed that are designed to primarily degrade an enemy's SA (pp. 370-371). Overall, the book shows the vital role that SA is thought to play in successful air-to-air combat.

KEYWORDS: air-to-air mission, aviation (military), avionics, pilot aiding, training

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194. Smallwood, W.L. (1993). *Warthog: Flying the A-10 in the Gulf War.* Washington, DC: Brassey's.

This book reviews the role played by A-10 squadrons in the 1991 Gulf War. Although used in several other missions, the A-10 was designed to be a close-air support aircraft. SA is only mentioned once (pp. 183-184), "I entered the kill box at 17,000 feet. I took the briefing at 17,000 feet and in the course of forty minutes of flying around I was down to 8,000 to 9,000 feet. As I went lower my SA [situational awareness] should have had a corresponding increase, but it didn't." Shortly after this, the aircraft was probably hit by a surface-to-air missile (SAM). In any case, the aircraft was hit and the pilot was forced to eject. The pilot was captured by the Iraqis.

KEYWORDS: air-to-ground mission, aviation (military), flight test

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195. Smith, K., and Hancock, P.A. (1994). Situation awareness is adaptive, externally-directed consciousness. In R.D. Gilson, D.J. Garland, and J.M. Koonce (Eds.), *Situational awareness in complex systems: Proceedings of a CAHFA Conference* (pp. 59-68). Daytona Beach, FL: Embry-Riddle Aeronautical University Press.

The authors address the issue of a definition for SA (p. 60): "We extend the account of Tenney, Adams, Pew, Huggins, and Rodgers (1992) to propose that: (i) SA is best defined as adaptive, externally-directed consciousness; and (ii) SA is the invariant at the core of an adapted agent's Neisser cycle that generates both up-to-the-minute knowledge and action that anticipates signals in the task environment." The remainder of the paper discusses the ramifications of this viewpoint of SA. The discussion is conducted within the framework of the ecological psychology movement. Representation of the SA invariant is demonstrated with an example from air traffic control.

KEYWORDS: air traffic control, cognitive processes, definition

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196. Smyth, C.C., Malkin, F.J., and DeBellis, W.B. (1990). Design considerations for a counterair situation awareness display for Army aviation. In *American Helicopter Society 46th Annual Forum Proceedings* (Volume II, pp. 921-930). Alexandria, VA: American Helicopter Society.

This article discusses the type of display needed to equip Army helicopters to be viable in an air-to- air combat role against enemy helicopters. The article assumes that situation information would be available to the helicopter through data links to off-board sensor systems. This information would then be used to guide tactics for a successful engagement. The information would be presented to the pilot on a "situational awareness digital map display" (p. 922). The information that needs to be presented on such a display, approaches to formatting the information, and the limits of current helicopter display technology are discussed.

KEYWORDS: air-to-air mission, avionics, display design, data fusion, data link, helicopter, pilot aiding

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197. Spick, M. (1988). *The ace factor: Air combat & the role of situational awareness.* Annapolis: Naval Institute Press.

This book is apparently intended for a mainstream audience. Much of the book is concerned with the question of what separates expert ace pilots from the remaining majority of normal military pilots. The author argues that the "ace factor" is better SA abilities. This is supported by a review of the history of air combat. The potential for improving SA in future air combat pilots is also discussed, generally within the framework of technological advancements in avionics and cockpit design.

KEYWORDS: air-to-air mission, aviation (military), avionics, cognitive measures, expertise, pilot aiding, training

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198. Stein, K.J. (1986, December 1). Complementary displays could provide panoramic, detailed battle area views. *Aviation Week & Space Technology, 125*(22), 111, 113, 115.

The article defines SA as (p. 113), "the knowledge available to the pilot on critical matters such as the overall tactical situation, his own mission profile, weapons status, the positions and objective of friendly aircraft, disposition and apparent objectives of hostile flights, presence of threats, refueling rendezvous and other mission data." Eugene Adam of McDonnell Aircraft is quoted as suggesting (p. 111), "Pilots are not so much overworked as they are underinformed." The article discusses two display concepts that could be combined to improve pilot SA: (1) a "Big Picture" cockpit display of about 300 square inches to provide an overview of the battle situation, and (2) a helmet-mounted HUD-like display for targeting weapon systems and detailed tactical capabilities. It is suggested that these display innovations could help to avoid the pervasive lack of SA that has resulted in two-thirds of the combat pilots being shot down by people they never saw.

KEYWORDS: aviation (military), big picture displays, definition, display design, helmet-mounted displays (HMDs), pilot aiding

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199. Steiner, B.A., and Camacho, M.J. (1989). Situation awareness: Icons vs alphanumerics. In *Proceedings of the Human Factors Society 33rd Annual Meeting* (Volume 1, pp. 28-32). Santa Monica, CA: Human Factors Society.

This research was conducted because the authors felt that much effort is put into developing new cockpit technologies which are not sufficiently evaluated as to whether they decrease workload or increase pilot effectiveness. This research examined how well and how quickly subjects (6 pilots, 6 engineers) could interpret information from alphanumeric and iconic displays which depicted various amounts of information. Probe questions were asked in two formats, one where the question preceded viewing of the display and one where the question followed the display presentation. For displays presenting only 2 or 4 bits of information, there was no difference in time needed to answer the question between display types. For 8, 16, and 32 bit displays, subjects required less time to answer questions with the iconic display, both to locate the answer to a question and to study the display for a question asked later. This research favors the use of iconic displays for heads-down cockpit instrumentation.

KEYWORDS: cognitive processes, display design, measurement, performance-based measures, questionnaire/survey data, retrospective measures, subjective measures, workload

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200. Steiner, B.A., and Dotson, D.A. (1990). The use of 3-D stereo display of tactical information. In *Proceedings of the Human Factors Society 34th Annual Meeting* (Volume 1, pp. 36-40). Santa Monica, CA: Human Factors Society.

This paper describes a study which investigated threat identification by pilots who were presented with 2-D and 3-D/stereo displays of tactical information. The hypotheses was that performance and situation awareness would increase with a 3-D presentation instead of a standard 2-D tactical situation display. In particular, this study focused on speed and accuracy in locating specific classes of targets. Nine subjects (current or former military fighter/test pilots) participated in the study in Lockheed's Weapon System Simulation Center at Rye Canyon, California. Results were not as expected; the 2-D display response times were faster and total errors were less. Nevertheless, in questionnaires and interviews, subjects preferred the 3-D display and felt that such a display gave a competitive advantage.

KEYWORDS: air-to-air mission, aviation (military), combat simulation, display design, measurement, performance-based measures, pilot aiding, pilot error, questionnaire/survey data, subjective measures, target identification

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201. Stiffler, D.R. (1987, April). *Exploiting situational awareness beyond visual range* (Student Report No. 87-2370). Maxwell Air Force Base, AL: Air Command and Staff College. (AD-B110786)

The author discusses issues associated with a definition of situation awareness for air combat. Numerous issues are discussed and several definitions are presented, but the author appears to settle on defining situation awareness as (p. 13), "the ability to envision the current and near-term disposition of both friendly and enemy forces." Situation awareness was related to the O-O-D-A loop concept of combat decision making. The O-O-D-A loop consists of cycling through the stages of Observe - Orient - Decide - Act. The orientation phase is emphasized as the most crucial to situation awareness. During orientation, the information from the observation stage is combined with knowledge to produce a mental image of the situation. In regard to situation awareness, two characteristics are emphasized by the author: measurability and exclusivity. Measurability is considered to be "remarkably easy; one only has to ask the pilot after the mission to evaluate his own SA" (p. 6). In practice, this approach requires a debriefing of the participants in a mission explaining the evolution of their mental pictures as they progressed through the mission. These mental pictures are compared to either a consensus view of other participating or observing pilots or to a playback of some record of the mission or both. The author cites a study that found a high correlation between pilots' self rating of situation awareness and the assessments of observing pilots as evidence of the validity of this approach. The author also cautions against trying to measure situation awareness at any one point in time because it can change rapidly throughout the mission. The characteristic of exclusivity of situation awareness suggests that in air-to-air combat only one side will tend to have good situation awareness at any point in time. This was not presented as a theoretical certainty, but as an empirical observation. As one side gains situation awareness in simulated air-to-air combat, they would tend to act in such a way as to disrupt the other side's O-O-D-A loop and thus diminish their situation awareness. Overall, the paper is notable for its strong ties to the operationally relevant aspects of situation awareness and its attempts to connect the concept of situation awareness to concepts of combat decision making.

KEYWORDS: aviation (military), cognitive processes, decision making, definition, measurement, mental models, retrospective measures, subjective measures

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202. Stiffler, D.R. (1988, Summer). Graduate level situational awareness. *USAF Fighter Weapons Review, 36*(2), 15-17, 20.

This article appears to be a summary of the Stiffler (1987) article. It presents the same main ideas and ties them even more directly to air combat tactics.

KEYWORDS: aviation (military)

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203. Stiles, G.J., and Pearson, R.P. (1986, December). Designing for situational awareness. *Defense Electronics, 18*(12), 84-86, 88.

The authors define SA as (p. 85), "a combatant's knowledge of the battlefield situation about him." They suggest that the SA concept can be usefully subdivided into SA about different aspects of the situation (such as, weapons' SA, flight performance SA, etc.). Within this framework they analyze the failure for some electronic warfare (EW) systems to gain favor within the cockpit environment. In many cases, the inclusion of new EW systems have been resisted by pilots and existing EW systems have deactivated by pilots in combat environments. The authors argue that the presentation of the EW system information has often not been compatible with the construction and maintenance of overall SA. They suggest that the displays must be better designed to aid SA. Among other suggestions, the authors argue that a good display should assist the pilot in visually locating any threats outside the cockpit and must provide easily understood and accurate range information.

KEYWORDS: aviation (military), definition, display design, pilot aiding

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204. Stratton, M.D., Wilson, G.F., and Crabtree, M.S. (1993). An analysis of physiological metrics in the study of pilot situational awareness. In *Proceedings of the Seventh International Symposium on Aviation Psychology* (Volume 2, pp. 901-905). Columbus: The Ohio State University.

The authors approached this study with the goal of determining whether physiological measurement techniques which are sensitive to mental workload can be used to indirectly measure SA. EEG, heart rate (interbeat interval), and eye blink (duration and rate) measures were used. Subjects were 12 college students. They performed a simulated flying task in a Simulator for Tactical Operations Research and Measurement (STORM) system. The out-the-window display varied between two "daylight" conditions (one with red and one with brown tanks), and a global satellite positioning (GPS) display. For half the trials, an audio signal warned subjects of a nearby surface-to-air missile (SAM), which indirectly indicated proximity to ground targets (tanks). The most difficult conditions showed an increase in power in the theta band relative to other bands. Therefore, the authors conclude that using EEG as an indirect measure of SA shows promise. The heart rate and eye blink measures were not sensitive to display conditions.

KEYWORDS: combat simulation, measurement, physiological measures, workload

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205. Sullivan, C., and Blackman, H.S. (1991). Insights into pilot situation awareness using verbal protocol analysis. In *Proceedings of the Human Factors Society 35th Annual Meeting* (Volume 1, pp. 57-61). Santa Monica, CA: Human Factors Society.

The authors related concepts concerning the relative roles of long-term and short-term memory in creating and maintaining situation awareness to techniques for collecting and analyzing verbal protocol information. Their hypothesis was stated as follows (p. 57), "Given that experienced pilots are more likely to have long-term memory structures that alleviate the load on working memory, it is expected that expert pilots will require less information from the intercept environment to maintain SA. Thus expert pilots will have fewer verbalizations regarding the updating and maintenance of intercept information." This hypothesis was tested by collecting concurrent verbal protocols from six expert and six novice F-16 pilots while they performed a variety of simulated air-to-air intercepts. Contrary to the hypothesis, no main effect of pilot experience was detected in the verbal protocol analysis. However, there was an interaction between pilot experience and number of enemy aircraft. Novices spoke much more than experts when confronted with two opponents, but verbalized about the same as experts when confronted with either one or four enemies. The results from this study can not be considered conclusive, but nevertheless suggest that verbal protocol analysis might be a promising avenue for future research.

KEYWORDS: expertise, cognitive processes, combat simulation, measurement, subjective measures, verbal protocols

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206. Tarrel, R.J. (1985). Human factors associated with runway transgressions. In *Proceedings of the Third Symposium on Aviation Psychology* (pp. 713-720). Columbus: The Ohio State University.

This article reported on the results of an analysis of runway transgression errors by commercial pilots that have been reported to NASA's Aviation Safety Reporting System (ASRS). A total of 104 ASRS runway transgression reports were analyzed. Each report was classified according to whether it involved any of three properties: (1) problems with the information transfer to the cockpit, (2) a lack of awareness by the crew, and/or (3) poor spatial judgment. The principle causes for reported runway transgressions were information transfer and awareness. It was often difficult to differentiate between these in practice. However, poor spatial judgment was not found to be a significant contributor to runway transgressions.

KEYWORDS: aviation (civilian), cognitive processes, measurement, pilot error, retrospective measures, subjective measures

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207. Taylor, R.M. (1989, October). *Situation awareness: Aircrew constructs for subjective estimation*. (Institute of Aviation Medicine Report No. 670). Farnborough, UK: RAF Institute of Aviation Medicine.

This paper is essentially the same as Taylor (1990) included in AGARD-CP-478 - Situation Awareness in Aerospace Operations and is reviewed under that citation.

KEYWORDS: attention, cognitive processes, definition, measurement, questionnaire/survey data, SART, subjective measures

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208. Taylor, R.M. (1990, April). Situational awareness rating technique (SART): The development of a tool for aircrew systems design. In AGARD-CP-478, *Situational Awareness in Aerospace Operations* (pp. 3-1 to 3-17). Neuilly Sur Seine, France: Advisory Group for Aerospace Research & Development. (AD-A223939)

The paper includes an extensive discussion of the role situation awareness plays in modern aviation settings. Definitional issues are discussed. In the conduct of the research, the following definition of situational awareness is used (p. 3-3): "Situational awareness is the knowledge, cognition and anticipation of events, factors and variables affecting the safe, expedient and effective conduct of the mission." (The authors also cite (p. 3-2) a SA definition from the HQ USAF AFISC/SE Safety Investigation Workbook: "Keeping track of the prioritized significant events and conditions in one's environment.") Knowledge extraction techniques were used to identify concepts that RAF aircrews felt were related to situation awareness. Analysis showed three major domains were related to situational awareness: Attentional Demands, Attentional Supply, and Understanding. Ten more specific constructs were identified as underlying the three domains. These constructs and domains were used to define the dimensions of the two variants of the Situational Awareness Rating Technique (i.e., the 10-Dimensional and 3-Dimensional variants). The two variants of SART allow the evaluator to select the most appropriate tool based on the degree of intrusiveness that can be tolerated. Research testing the SART techniques in the evaluation of real tasks is suggested.

KEYWORDS: attention, cognitive processes, definition, measurement, questionnaire/survey data, SART, subjective measures

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209. Taylor, R.M. (Ed.) (1991, December). *Situational awareness in dynamic systems* (Institute of Aviation Medicine Report No. 708). Farnborough, UK: RAF Institute of Aviation Medicine.

This document consists of five four-page papers presented at the Special Session on Situational Awareness at the 11th Congress of the International Ergonomics Association, Paris, France. Although all five papers were written in an aircrew systems context, the methods and findings are applicable to systems in other dynamic environments.

Situation Awareness in Dynamic Systems, by M.R. Endsley, focuses on situation awareness as a critical step in the decision making process. Designers of dynamic systems should maximize SA and concentrate on "what would the operator ideally like to know?"

M. Fracker and M.A. Vidulich, in *Measurement of Situation Awareness: A Brief Review*, explain the three major approaches to assessing SA. The authors discuss explicit, implicit, and subjective rating measures, including strengths, weaknesses, and cautions for each type measure.

In *Subjective Measurement of Situational Awareness*, R.M. Taylor and S.J. Selcon discuss the key problems of subjective measures of SA: validity (how well a technique measures what it is actually intended to measure); sensitivity (capacity of a measure to discriminate variations in SA); and diagnosticity (how well a measure discriminates causes of differences in SA). The authors also discuss their Situational Awareness Rating Technique (SART), including its strengths and weaknesses.

In *Situation Assessment and Situation Awareness in a Team Setting*, K.L. Mosier and T.R. Chidester discuss an investigation of decision-making strategies employed by commercial air transport crews. The investigation focused on indicators of situational assessment, represented by information solicitation and transfer communications occurring during simulated inflight emergencies.

S.J. Selcon and R.M. Taylor discuss SA in the context of a decision support system (DSS) in *Decision Support and Situational Awareness*. Their paper addresses the following key issues of the expert system/ human operator relationship: trust in the system; the representation of uncertainty; communication; and appropriate level of autonomy.

KEYWORDS: aviation (civilian), cockpit resource management (CRM), cognitive processes, decision aiding, decision making, implicit measures, measurement, memory probe measures, pilot aiding, SAGAT, SART, subjective measures, team decision making, team SA

210. Taylor, R.M., and Selcon, S.J. (1990a). Cognitive quality and situational awareness with advanced aircraft attitude displays. In *Proceedings of the Human Factors Society 34th Annual Meeting* (Volume 1, pp. 26-30). Santa Monica, CA: Human Factors Society.

This paper presents two studies comparing "cognitive quality" and measures of SA with four different types of attitude indicator displays. In both studies, attitude was presented tachistoscopically by depictions of HUD, an ADI ball, an "outside-in" picture of an F-18 model, and a pictorial command indicator, viewed line astern as by a "buddy" aircraft, again using F-18 model pictures. In the first study, subjects (16 student pilots) were asked to make a stick input to recover to straight and level flight. Time and direction of initial stick inputs were measured, along with subjective SA via the Situational Awareness Rating Technique (SART). The same measures were used for Study 2, but subjects were shown two pictures and asked to return the aircraft to the attitude shown in the first one.

KEYWORDS: attitude displays, cognitive processes, decision making, display design, measurement, performance-based measures, pilot aiding, SART, subjective measures

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211. Taylor, R.M., and Selcon, S.J. (1990b). Understanding situational awareness. In E.J. Lovesey (Ed.), *Proceedings of the Ergonomics Society's 1990 Annual Conference* (pp. 105-111). London: Taylor and Francis.

This is a theoretical paper which presents concepts and summarizes work performed at the RAF Institute of Aviation Medicine (IAM) in the field of SA. Taylor and Selcon posit that SA is a global paradigm which gives us a framework for studying problems, issues, and solutions associated with aircrew systems design. Studies are summarized which demonstrate the benefit of "redundancy gain" and "cognitive integrality" in HUD pitch ladder design features. Intelligent decision-aiding for the pilot, for helping to resolve uncertainty and therefore reduce workload, is discussed as a technology which is ripe for SA applications. A recent study at the IAM showed that decision-making time was reduced when "probability tags" were presented for different options. The process undertaken to develop the Situational Awareness Rating Technique (SART) is outlined briefly; because this measurement technique is derived from aircrew knowledge and experience, the authors feel that the constructs which make up the SART are in effect a definition of SA. Taylor and Selcon mention three studies which "showed that SART had utility in predicting performance on skill, rule, and knowledge based tasks;" these studies are discussed in greater detail in Selcon and Taylor, 1989. The authors conclude by proposing that SART is a noteworthy concept because it provides definition along with a measurement tool which can be used effectively in the system's design process. They do stipulate that more research should be done to "develop a method of conjoint scaling for the SART dimensions."

KEYWORDS: attitude displays, cognitive processes, decision aiding, decision making, definition, display design, measurement, pilot aiding, SART, subjective measures, workload

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212. Taylor, R.M., and Selcon, S. (1991). Subjective measurement of situational awareness. In *Designing for Everyone: Proceedings of the 11th Congress of the International Ergonomics Association* (Volume 1, pp. 789-791). Paris, France: Taylor & Francis.

This paper, along with 4 other SA related papers presented at the Congress, were reprinted in Taylor (1991) and is reviewed under that listing.

KEYWORDS: measurement, SART, subjective measures

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213. Taylor, R.M., and Selcon, S.J. (1994). Situation in mind: Theory, application and measurement of situational awareness. In R.D. Gilson, D.J. Garland, and J.M. Koonce (Eds.), Situational awareness in complex systems: Proceedings of a CAHFA Conference (pp. 69-77). Daytona Beach, FL: Embry-Riddle Aeronautical University Press.

The authors use a "question and answer" format to address what they perceive to be the key issues in SA. The four main questions discussed are (p. 69):
"(1) What is the problem?
(2) What is the relevant theory?
(3) What are the consequences of the theory?
(4) Do the theoretical predictions fit experience and the experimental data?"
The problem is said to be that lack of SA is often cited as a causal factor in errors and reduced mission effectiveness. The influence of SA (or its lack) on system performance show up in numerous different ways that seem to make defining SA very difficult. The authors review examples of settings in which the SA concept has been evoked and various approaches to defining SA. The authors own approach to defining SA depended on an empirical process of extracting notions of SA from pilots (see Taylor, 1989). In discussing theories of SA, the authors point out that most theories of SA have utilized the following three basic psychological concepts: limited attentional resources, working memory (or short term memory), and long term memory (especially schema in long term memory). However, the authors suggest that several other psychological theories could be applied to the problem of SA. These additional theories include attentional priority, perceptual organization, perceptual control theory, mental models, semantic memory, spatial information processing, dynamic mental representation, human error, naturalistic decision making, and situated acts. In considering the consequences of the current theoretical state-of-affairs, the authors state (p. 73): "Since the theory of SA appears selective and fragmented, the consequences are that, as yet, there are few generalizable conclusions or predictions that seem to be more than common sense at best, and self-fulfilling prophesies at worst." In trying to answer whether the SA research findings fit the theoretical predictions, the authors suggest that answers to this question are limited by our ability to measure SA. SART is presented as a potential SA metric.

KEYWORDS: attention, cognitive processes, decision making, definition, measurement, mental models, SART, schema, subjective measures

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214. Tenney, Y.J., Adams, M.J., Pew, R.W., Huggins, A.W.F., and Rogers, W.H. (1992, July). *A principled approach to the measurement of situation awareness in commercial aviation* (NASA Contractor Report 4551). Washington, DC: National Aeronautics and Space Administration.

This report covers information processing theories related to pilot SA as well as several suggested strategies for measuring SA. From a cognitive standpoint, Tenney et al. distinguish the process of SA (situation assessment) from the product, which is the "state of awareness with respect to information and knowledge." Definitions of SA are also categorized according to this dichotomy. The elaboration on information processing theory merges Neisser's theory of the perceptual cycle with principles from Sanford and Garrod's theory of memory and attention. The result is a framework which nicely illustrates pilot assessment and awareness, and which implies that the product continually influences the process. Effect of expertise in overcoming ambiguity in SA is treated with a discussion of seven compensatory strategies used by highly experienced pilots to overcome limits of performance in multi-task situations. Then specific strategies for measuring SA are presented and illustrated through detailed examples. The three strategies are: (1) measures derived from scenario manipulations, (2) direct measures such as queries and recall of displays, and (3) model-based measures. A combination of the three measures is suggested as an effective approach, and the use of these strategies in two current studies is outlined. Recent aircraft accident reports are referenced repeatedly, relating the causes of these accidents to measurement approaches. Finally, the report delves into effects of present-day cockpit automation on pilot SA, and concludes by extrapolating individual pilot SA principles into the team or crew domain. This report will be of use to researchers interested in information-processing theories as applied to SA, and to those who seek to design an effective suite of SA measures, for a variety of system design applications.

KEYWORDS: attention, aviation (civilian), avionics, cognitive processes, expertise, measurement, memory probe measures, performance-based measures, schema, team SA

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215. Ulbrich, E.A. (1990). Situational awareness in large aircraft. In *Proceedings - Cockpit Displays and Visual Simulation* (SPIE Proceedings Series Volume 1289, pp. 2-10). Bellingham, WA: Society of Photo-Optical Instrumentation Engineers.

This paper discusses the possible use of and artificial intelligence system, called Adaptive Network for Avionics Research Management (ANARM), to enhance the SA of pilots flying large transport aircraft in a high-threat combat environment. In discussing the development of the program, the authors state (p. 3): "In general, as the number of threatening aircraft and ground-based threats increased, the system evolved from a pilot-advisory system to a closed-loop operational system with pilot overview and management. To enhance a pilot's situational awareness, the system relies heavily on interactive displays and controls." Several display design approaches were evaluated for this system. Among the four conclusions that are listed the authors cite as an accomplishment (p. 4), "Increased situational awareness due to data fusion using 3-D displays and user-variable viewpoints. This is probably the most important of the four accomplishments."

KEYWORDS: aviation (military), avionics, data fusion, display design, pilot aiding

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216. Venturino, M., Hamilton, W.L., and Dvorchak, S.R. (1990, April). Performance-based measures of merit for tactical situation awareness. In AGARD-CP-478, *Situational Awareness in Aerospace Operations* (pp. 4-1 to 4-5). Neuilly Sur Seine, France: Advisory Group for Aerospace Research & Development. (AD-A223939)

Using a data base from an evaluation of a new missile system within a high-fidelity simulation, the authors explored the inter-relationships among situation awareness ratings, a performance-based measure of merit, and an overall mission effectiveness score. Situation awareness was rated by both the pilot performing the mission and by expert observers watching the mission. Correlations between self-reported situation awareness and mission effectiveness was moderate. Observer ratings appeared to correlate somewhat more strongly with mission effectiveness. Interestingly, pilots that rated their situation awareness as low or average tended to be in agreement with the mission effectiveness score. However, those pilots that rated their situation awareness as high had mission effectiveness scores ranging from poor to superior. As the authors point out (p. 4-3): "Good SA, as rated by the pilot appears to be a necessary but not sufficient contributor to good pilot performance." Predicting overall mission effectiveness was greatly enhanced when the situation awareness ratings were considered along with information about the performance-based measure of merit (fire point selection).

KEYWORDS: aviation (military), combat simulation, measurement, performance-based measures, subjective measures

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217. Venturino, M., and Kunze, R.J. (1989). Spatial awareness with a helmet-mounted display. In *Proceedings of the Human Factors Society 33rd Annual Meeting* (Volume 2, pp. 1388-1391). Santa Monica, CA: Human Factors Society.

No formal definition is presented, but the authors propose a "crude dichotomy" for decomposing situation awareness: state awareness of aircraft subsystems, and spatial awareness of relevant aircraft. The paper reported two laboratory studies of human spatial awareness within a virtual world constructed by a helmet-mounted display (HMD). The field-of-view of the HMD was varied along with the memory load of potential targets that had to be relocated back to their original position. In general, the HMD field-of-view had a large effect on the amount of time the subject required to study the environment, but little effect on the accuracy of the placement of the target objects. However, replacement error was significantly affected by increasing the memory load of potential targets. The results suggest that a larger field-of-view permits faster construction of good spatial awareness.

KEYWORDS: definition, display design, helmet-mounted displays (HMDs), measurement, performance-based measures

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218. Vidulich, M.A., Crabtree, M.S., and McCoy, A.L. (1993). Developing subjective and objective metrics of pilot situation awareness. In *Proceedings of the Seventh International Symposium on Aviation Psychology* (Volume 2, pp. 896-900). Columbus: The Ohio State University.

This study compares techniques used in assessing situational awareness. The authors based their work on the logic of early mental workload studies. Situation awareness was measured using several different tools. After a minimum of 16 hours training, twelve college-aged subjects flew three sessions (two or three blocks per session, six flights per block) of simulated air-to-ground attacks in the Simulator for Tactical Operations Research and Measurement (STORM). Each flight consisted of a low-level route terminating in a cannon attack on six enemy vehicles ("tanks"). Display conditions (tank color, target display in aircraft) were varied in order to affect the difficulty in obtaining SA. Objective SA was measured by explicit memory probes (freezing simulation and asking for relevant information) and implicit probes (based on signal detection task measures of effective cannon use). Subjective SA measures consisted of the 10-dimensional Situation Awareness Rating Technique (SART), the Overall-SART Scale, a unidimensional Overall-SA scale, and the SA Subjective Workload Dominance (SA-SWORD) technique. The results of the implicit probe are not reported here, while the results of the memory probe were labeled as "disappointing." Overall-SA measures did not show any display effects; the authors state that this "implies that a simple unidimensional SA scale is not an effective SA measure." The Overall-SART ratings were a sensitive metric but lacked a statistically significant test-retest reliability.

KEYWORDS: air-to-ground mission, aviation (military), combat simulation, implicit measures, measurement, memory probe measures, performance-based measures, reliability, SART, SA-SWORD, subjective measures

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219. Vidulich, M.A., and Hughes, E.R. (1991). Testing a subjective metric of situation awareness. In *Proceedings of the Human Factors Society 35th Annual Meeting* (Volume 2, pp. 1307-1311). Santa Monica, CA: Human Factors Society.

The purpose of the research described in this paper was to test a subjective situation awareness (SA) metric, the SA Subjective WORkload Dominance (SWORD) technique. This technique applied SWORD workload assessment principles to an evaluation of two different cockpit displays. The subjects, twelve Air Force pilots, used Fire Control Radar (FCR) and Horizontal Situation Format (HSF) displays during eight simulator flights, four flights per display. The flights consisted of ingress (low threat: no surface-to-air missile (SAM) attacks, enemy armed with short-range missiles) and engagement (beyond visual range, multiple-threat combat, high threat: SAM attacks, enemy fighters with advanced long-range missiles). After the trials, the subjects performed SA-SWORD ratings on combinations of display, segment and threat. Pilots rated the HSF as providing better SA. The authors state that this study was a first attempt to use SA-SWORD as an SA metric and that they have not reached a final conclusion concerning test sensitivity. The test did show, however, good SA-SWORD sensitivity to display manipulation and good inter-rater reliability, suggesting that SA-SWORD can be useful as a subjective tool. Pilot comments regarding the value of SA-SWORD were generally neutral or positive.

KEYWORDS: air-to-air mission, aviation (military), combat simulation, measurement, reliability, SA-SWORD, subjective measures, workload

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220. Vidulich, M.A., Stratton, M., Crabtree, M., and Wilson, G. (1994). Performance-based and physiological measures of situational awareness. *Aviation, Space, and Environmental Medicine, 65*(5, Supplement), A7-A12.

This paper is a more detailed presentation of portions of the project discussed in Stratton, Wilson, and Crabtree (1993) and Vidulich, Crabtree, and McCoy (1993).

KEYWORDS: air-to-ground mission, aviation (military), combat simulation, implicit measures, measurement, memory probe measures, performance-based measures, physiological measures, SART, subjective measures, workload

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221. Waag, W.L., and Houck, M.R. (1994). Tools for assessing situational awareness in an operational fighter environment. *Aviation, Space, and Environmental Medicine, 65*(5, Supplement), A13-A19.

This article is a detailed review of one of the essential components of the Armstrong Laboratory's Situation Awareness Integration (SAINT) team's research project. The authors recount the extensive development and data collection work that was performed to create a SA criterion measure for assessing over 200 F-15 pilots. This criterion measure is called the Situational Awareness Rating Scales (SARS). The SARS were developed in several parallel forms; self-rating, peer rating, and supervisor rating. Reliability of the SARS was found to be strongly positive. Also, the SARS was found to be significantly related to flight experience and current flight qualification. A subset of the SARS evaluated F-15 pilots were selected for a series of simulated combat engagements. This planned follow-on should provide an opportunity to assess the predictive validity of the SARS scores. (Please refer to Grant McMillan's paper in this report for an overall review of the SAINT team research program.)

KEYWORDS: aviation (military), measurement, subjective measures

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222. Waddell, D. (1979, Winter). Situational awareness. *USAF Fighter Weapons Review*, pp. 3-6.

After noting that SA had become a commonly discussed issue during debriefings, the author evaluates the concept of SA. A simple definition is offered (p. 3), "Situational awareness is an assessment of a situation based on the best possible information." The author breaks SA down into three categories: Actual (based on direct sensory information), Extrapolated (mentally extrapolating changes in aspects of the situation that are not at the moment available to direct sensory input), and Best Guess (using predictability to generate rules of thumb). The author proposes methods for improving pilot SA. Most suggestions involve tactics, or training ideas. The use of debriefing to increase SA for future flighters and to identify possible training needs is highlighted.

KEYWORDS: aviation (military), cognitive processes, definition, measurement, mental models, retrospective measures, subjective measures, training

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223. Ward, G.F., and Hassoun, J.A. (1990, July). *The effects of head-up display (HUD) pitch ladder articulation, pitch number location and horizon line length on unusual attitude recoveries for the F-16* (Tech. Report No. ASD-TR-90-5008). Wright-Patterson Air Force Base, OH: Aeronautical Systems Division. (AD-A268666)

Along with assessing the impact of different HUD formats on the attitude recovery performance and subjective ratings of workload, the authors included a subjective situation awareness scale. The subjective awareness scale was a nine-point scale with verbal descriptors ranging from "Decidedly DISAGREE" to "Decidedly AGREE." The pilots' responses were converted to numerical values based on the recommendations from Army Manual P-71-1 (Training and human factors research on military systems: Questionnaire construction manual). After randomly selected attitude recoveries, the pilot was asked to use the scale to respond to the statement (p. 10): "I experienced no confusion with this pitch ladder configuration and was easily able to recover to straight and level flight." The scale was sensitive to the different HUD pitch ladder configurations, but the format that was rated the best for attitude awareness was also the format that produced the greatest number of inverted recoveries. As the authors put it (p. 30): "Based on the SA results, the pilots felt that their situation awareness was very good when flying with the fully articulated pitch scale while their performance unequivocally indicated the opposite.... These results indicate that, in its present form, the SA tool is not a sufficient indicator of pilot situation awareness."

KEYWORDS: attitude displays, aviation (military), display design, measurement, performance-based measures, pilot aiding, questionnaire/survey data, retrospective measures, subjective measures, workload

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224. Weinstein, L.F., Ercoline, W.R., Evans, R.H., and Bitton, D.F. (1992). Head-up display standardization and the utility of analog vertical velocity information during instrument flight. *The International Journal of Aviation Psychology, 2,* 245-260.

As part of a program to create a standard symbol set for U.S. Air Force Head-Up Displays (HUDs), this project examined different ways to present vertical velocity information on the HUD. Performance and subjective data both suggested that combining the vertical velocity information within the altimeter arc was best. The authors suggest that a beneficial side-effect of this would be a reduction of display clutter. This was seen as a benefit because (p. 257), "A reduction in display clutter allows the pilot to view more of the outside world through the HUD, enabling the pilot to maintain a higher level of spatial orientation and overall situational awareness."

KEYWORDS: aviation (military), display design, measurement, performance-based measures, pilot aiding, retrospective measures, subjective measures

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225. Wells, M.J., and Venturino, M. (1989). The effects of increasing task complexity on the field-of-view requirements for a visually coupled system. In *Proceedings of the Human Factors Society 33rd Annual Meeting* (Volume 1, pp. 91-95). Santa Monica, CA: Human Factors Society.

The authors tested the hypothesis that as task demands were increased by combining a visual search and replacement task with a tracking task in a dual-task, the value of a larger field-of-view (FOV) in a head-coupled helmet-mounted display would increase. One measure of the FOV requirement was "spatial awareness," which was assessed by target replacement accuracy. The authors concluded (p. 95), "Despite the increased demands imposed by the small FOVs, subjects managed to develop the same degree of spatial awareness, as evidenced by the replacement error, as with the large FOVs. But at a cost. The cost was an increase in tracking error with the small FOVs."

KEYWORDS: display design, helmet-mounted displays (HMDs), measurement, performance-based measures

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226. Wells, M.J., Venturino, M., and Osgood, R.K. (1988). Using target replacement performance to measure spatial awareness in a helmet-mounted simulator. In *Proceedings of the Human Factors Society 32nd Annual Meeting* (Volume 2, pp. 1429-1433). Santa Monica, CA: Human Factors Society.

The authors studied spatial awareness as a component of situational awareness. The research was conducted within a virtual world environment created by a helmet-mounted display (HMD). The experiment evaluated the effects of field-of-view size, background, number of target objects, and amount of search time on the performance of a replacement task (i.e., replacement of objects to their original location). Results showed that replacement performance was sensitive to all of the independent variables, suggesting that it was a good metric of spatial awareness.

KEYWORDS: display design, helmet-mounted displays (HMDs), measurement, performance-based measures

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227. Whitaker, L.A., and Klein, G.A. (1988, April). Situation awareness in the virtual world: Situation assessment report. In *Proceedings of the Psychology in the Department of Defense Eleventh Symposium* (Tech. Report No. USAFA-TR-88-1, pp. 321-325). Colorado Springs, CO: US Air Force Academy. (AD-A198723)

The authors propose tools for the evaluation of the needs of pilots working with future-generation virtual world cockpits. The tools are the Critical Decision Method ("a pool of techniques and types of probes that elicit detailed, specific information about the conscious processes and strategies that underlie real-world decision making" (p.323)) and the Situation Assessment Report ("a formalism for dynamic decisions by tracing the evolution of the decision maker's situation awareness as new cues and information are received" (p. 324)). The tools grew out of a research program studying expert decision makers in naturalistic settings.

KEYWORDS: cognitive processes, decision making, expertise, measurement, retrospective measures, subjective measures

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228. Wickens, C.D. (1992, December). Workload and situation awareness: An analogy of history and implications. *INSIGHT: The Visual Performance Technical Group Newsletter, 14*(4), 1-3.

The author argues that the concepts of workload and situation awareness are similar in that both concepts evolved out of the operational community to become important topics in the research community and both concepts involve an inferred mental construct. However, whereas workload was the "hot issue" of the 1980s, situation awareness appears to be the issue of the 1990s. The author suggests a definition for situation awareness (p. 2): "Situation awareness refers to the ability to rapidly bring to consciousness those characteristics that evolve during a flight." The author emphasizes the word "evolve" in order to distinguish the information involved in situation awareness from simple declarative and procedural knowledge. The author also emphasizes that the "ability to bring" phrase refers to information that may be immediately available and important, but not reside in consciousness at the moment. It is suggested that the overall domain of situation awareness can be decomposed into at least four topics: Navigation awareness, Systems awareness, Task awareness, and Temporal awareness. The available measurement techniques and some potential application areas are briefly discussed.

KEYWORDS: cognitive processes, definition, measurement, workload

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229. Wickens, C.D., and Flach, J.M. (1988). Information processing. In E.L. Wiener and D.C. Nagel (Eds.), *Human factors in aviation* (pp. 111-155). San Diego, CA: Academic Press.

This paper provides a major review of the relevance of human information processing theory to aviation. In the discussion of decision making in aviation, the authors suggest a model that includes "situation assessment" as a major component (see Figure 5.2, p. 128). Situation assessment is seen to be problematic if it is based on the operation of heuristics rather than based on an appreciation of the reliability of the various cues present in a situation. Summarizing the role of situation assessment in decision making, the authors state (p. 132), "Instead of using cue reliability as a basis for choosing their hypothesis, people more often focus attention most heavily on those cues that are physically salient..., and those that are likely to confirm the hypothesis that was already tentatively formed.... If those cues, by chance or by design, also happen to be quite reliable, then the assessment of the situation will likewise be accurate; but if they are not reliable, and their indicated diagnosis is wrong, then even the best-intended decision of what action to take may lead to disaster because it will be based on a faulty assessment of the world."

KEYWORDS: attention, cognitive processes, decision making

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230. Wiener, E.L. (1993). Life in the second decade of the glass cockpit. In *Proceedings of the Seventh International Symposium on Aviation Psychology,* (Volume 1, pp. 1-7). Columbus: The Ohio State University.

In the course of a keynote speech on the history and design of glass cockpits, the author touches briefly upon the topic of SA. The author takes issue with the common tendency of researchers to propose that advanced avionics in the commercial airline cockpit might degrade SA. One problem noted by the author is the lack of a clear definition of SA. The author suggests that (p. 4), "you can bring a panel discussion on the subject to a stand-still by merely asking the speaker or the panel what they mean by the 'situational awareness'." The author contends that SA is usually enhanced by the automation in glass cockpits. For example (p. 4), "Think of the ability to instantly locate the closest adequate airfield in the event of an extreme emergency. I have a name for what can be obtained from that type of information: I call it situational awareness." Other similar examples are cited.

KEYWORDS: aviation (civilian), avionics, definition, pilot aiding

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231. Wise, J.A., Guide, P.C., Abbott, D.W., and Ryan, L. (1993). Automated corporate cockpits: Some observations. In *Proceedings of the Human Factors and Ergonomics Society 37th Annual Meeting* (Volume 1, pp. 6-10). Santa Monica, CA: Human Factors and Ergonomics Society.

This article discusses the results of a survey to determine the effects of automation in the cockpits of corporate aircraft. The surveys were distributed to about one-quarter of the population of corporate pilots. A change in SA as a function of automation was mentioned by some of the respondents. The authors stated the SA result as (p. 8), "many comments report that automation has contributed to better situational awareness (which they seem to only think of in terms of navigation); increasing their ability to become more aware of the aircraft's status in real time."

KEYWORDS: aviation (civilian), avionics, measurement, pilot aiding, questionnaire/survey data, subjective measures

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232. Zacharias, G.L., Miao, A.X., Riley, E.W., and Osgood, R.K. (1992, November). *Situation awareness metric for cockpit configuration evaluation* (Tech. Report No. AL-TR-1993-0042). Wright-Patterson Air Force Base, OH: Armstrong Laboratory. (AD-B176582)

This report reviews the development of a computational model approach for evaluating the impact of cockpit display changes on pilot SA. Enabling technologies that were evaluated for possible contribution to the model included: modern estimation models, artificial neural networks, Bayesian belief networks, expert systems, and object-oriented system description languages. A proof-of-concept demonstration of the approach was used to evaluate the impact of a decision aid on performance of a beyond visual range (BVR) air-to-air engagement. Recommendations for follow-on efforts are discussed.

KEYWORDS: air-to-air mission, aviation (military), decision aiding, decision making, measurement, modeling, pilot aiding

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233. Zenyuh, J.P., Reising, J.M., Walchli, S., and Biers, D. (1988). A comparison of a stereographic 3-D display versus a 2-D display using an advanced air-to-air format. In *Proceedings of the Human Factors Society 32nd Annual Meeting* (Volume 1, pp. 53-57). Santa Monica, CA: Human Factors Society.

This research examined whether the use of stereoscopic displays would enhance the development of pilot SA. SA was defined as (p. 53), "the ability to visually search a spatial quadrant of the air-to-air situation display relative to the ownship symbol and identify the aircraft symbols in a given target group found in that quadrant." The research was conducted in laboratory simulator. The subjects performed the visual search task while flying the aircraft under simulated Instrument Flight Rules (IFR) conditions. Performance measures from both tasks improved when the presentation of the visual search task was stereoscopic. This suggests that the inclusion of stereoscopic information facilitated the development of SA from the display.

KEYWORDS: air-to-air mission, aviation (military), combat simulation, definition, display design, measurement, performance-based measures, pilot aiding, target identification

KEYWORD GLOSSARY

3-D Audio Displays - The article discusses the potential use of 3-D audio displays to improve SA.

Air Combat Maneuvering (ACM) - The article discusses the role of SA in ACM.

Air Traffic Control - The article discusses SA in air traffic control.

Air-to-air Mission - The article discusses the role of SA in air-to-air combat and/or uses a moderate to high fidelity simulation of air-to-air combat as an experimental task.

Air-to-ground Mission - The article discusses the role of SA in air-to-ground combat or uses a moderate to high fidelity simulation of air-to-ground combat as an experimental task.

Attention - The paper discusses the relationship between attention and SA

Attitude Displays - The article discusses the effects of aircraft attitude displays on pilot SA.

Automation - Refer to ***Avionics*** for applications of automation to aircraft. Also, many of the ***Air Traffic Control*** citations discuss an application of automation.

Aviation (Civilian) - The article discusses SA in the cockpit of non-military fixed-wing commercial aircraft. This would include general aviation, commercial aviation, corporate aviation or any other article that discussed SA in aviation that did not specify a military context.

Aviation (Military) - The article discusses SA in the cockpit of fixed-wing military aircraft.

Avionics - The article discusses the effects of aircraft avionics on pilot SA or discusses the application of avionics technology to non-aircraft systems.

Battlefield SA - The article discusses the role of SA in land-based Army battles.

Big Picture Displays - The article discusses the possible effects of large-area displays on operator/pilot SA.

Cockpit Resource Management (CRM) - The article discusses the effects of CRM on aircrew SA.

Cognitive Processes - The article proposes or discusses theories or some hypothesis concerning the role of cognitive process in creating or maintaining SA.

Combat Simulation - The article discusses an SA experiment that was performed using a combat simulator of moderate to high fidelity.

Crew Resource Management (CRM) - Refer to ***Cockpit Resource Management (CRM)***

Data Fusion - The article discusses the effects of data fusion on SA. Data fusion is the combination of information from multiple sources into one display.

Data link - The article discusses the effects of data link on SA. Data Links are digital communications from outside an aircraft that are used by the aircraft's avionics and/or presented on the aircraft's displays. Potential sources for the communications include other aircraft, air traffic control, ground stations, or satellites.

Decision Aiding - The article discusses the use of technology to improve SA and thus make more effective decisions and/or make decisions more easily.

Decision Making - The article discusses the relationship between SA and the cognitive process of decision making.

Definition - The article either proposes a specific definition for SA or substantively discusses components of SA.

Design Guidelines - The article proposes specific guidelines for improving SA in human-machine systems.

Display Design - The article discusses some aspect(s) of display design that affects SA in human-machine systems.

Expertise - The article discusses the relationship between expertise and SA.

Explicit Measures - Refer to ***Memory Probe Measures***.

Flight Test - The article discusses the role of SA in the design or measurement of a flight test program or discusses observations about SA that resulted from a test flight of an aircraft.

Fratricide - The article discusses the possible link between SA deficiencies and combat fratricide (i.e., attacks upon friendly forces).

Helicopter - The article discusses the role of SA in the operation of rotary-wing aviation.

Helmet-Mounted Displays (HMDs) - The article discusses the potential effects of helmet-mounted displays (HMDs).

Implicit Measures - The article either substantively discusses the potential usefulness of implicit signal detection measures of SA or reviews an evaluation that used an implicit measure of SA. The signal may be either an additional arbitrary signal or an embedded aspect of the task.

Individual Differences - The article either presents results of an evaluation of using selection tests to identify individuals with generic abilities conducive to good SA or substantively discusses the prospects for such tests.

Measurement - The article either presents results from a SA evaluation using either specific SA measures or a general approach to SA measurement that could be applied in other settings, or the article substantively discusses important issues for the measurement of SA.

Memory Probe Measures - The article either substantively discusses the potential usefulness of explicit memory probe measures of SA or reviews an evaluation that used memory probes as a measure of SA.

Mental Models - The article discusses the relationship between mental models (or some similar form of internal mental representation) and SA.

Modeling - The article discusses a model that attempts to predict the SA achievable based on a set of attributes of the situation or the system operator.

Multiple Resource Theory - The article discusses the relationship between multiple resource theory and SA.

Naval SA - The article discusses the role of SA in water-based Naval battles.

Performance-Based Measures - The article either substantively discusses the potential usefulness of objective task performance as a measure of SA or reviews an evaluation that used objective task performance as a measure of SA. In some cases, the performance measures might be used as a criterion for judging the validity of other SA measures.

Physiological Measures - The article either substantively discusses the potential usefulness of physiological measures of SA or reviews an evaluation that used physiological measures to measure SA.

Pilot Aiding - The article discusses how some aspect(s) of the design of the cockpit's displays, controls, avionics, software etc. could enhance the pilot's SA. In some cases, the article might discuss how to avoid the potential SA degradation that could occur from cockpit changes.

Pilot Error - The article discusses the relationship between pilot SA and the production of pilot error.

Questionnaire/Survey Data - The article discusses the use of questionnaire or surveys to assess SA and/or reviews SA data collected by questionnaire, survey, or interviews.

Reliability - The article presents data on the reliability of at least one SA measurement technique.

Retrospective Measures - The article either substantively discusses the potential usefulness of retrospective recall of a task or mission as a measure of SA or reviews an evaluation that used retrospective measures as a measure of SA. These are similar to ***Questionnaire/Survey Data***, but differ in that they are focused on specific events (usually, but not always, events within the experiment). In some cases, this might refer to reports of actual operational incidents.

Review Paper - The article includes substantive comparative review of the results and/or concepts related to SA that are expressed in other articles by other authors.

SAGAT - The article either substantively discusses the potential usefulness of the Situation Awareness Global Assessment Technique (SAGAT).

SART - The article either substantively discusses the potential usefulness of the Situation Awareness Rating Technique (SART) or reviews an evaluation that used SART or employs the technique in a study.

SA-SWORD - The article either substantively discusses the potential usefulness of the Situation Awareness variant of the Subjective WORkload Dominance technique (SA-SWORD) or reviews an evaluation that used SA-SWORD as a measure of SA.

Schema - The article discusses the relationship between schemata and SA.

Signal Detection Probe Measures - Refer to ***Implicit Measures***.

Subjective Measures - The article either substantively discusses the potential usefulness of subjective measures of SA or reviews an evaluation that used subjective measures. Subjective measures include questionnaires/survey data, retrospective measures, verbal protocols, or subjective ratings.

Target Identification - The article reviews the role that identifying potential targets plays in maintaining a pilot's SA.

Team Decision Making - The article discusses the contribution played by SA in the decision-making of teams.

Team SA - The article discusses the factors that affect the shared SA across multiple members of a team.

Training - The article either presents results of an evaluation of using training to improve SA or substantively discusses the prospects for such training. The training program might either be aimed at improving generic SA abilities of the individuals or might be aimed at improving SA within a specific task domain.

Verbal Protocols - The article either substantively discusses the potential usefulness of verbal protocols as a measure of SA or reviews an evaluation that used verbal protocols as a measure of SA.

Workload - The article either discusses a hypothesis concerning the relationship between SA and mental workload and/or discusses an evaluation that used both SA and workload measures for assessment.

KEYWORD INDEX

(NOTE: The numbers following each keyword are citation numbers, not page numbers.)

AUTHOR INDEX

(NOTE: The numbers following the author's name refer to citation numbers, not page numbers.)